Characterisation and modeling of cattle movements in Cameroon

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Dedication

In memory of my mother, who really used to bridge between the extraordinary and the ordinary.

Declaration

This thesis is submitted to the University of Edinburgh in accordance with the requirements for the degree of Doctor of Philosophy in the faculty of Medicine and Veterinary Medicine. The work presented is the work of the author except where stated otherwise by reference and/or acknowledgement. Any included publications and any work presented, which has been conducted by (or in collaboration with) others is explicitly acknowledged. The candidate's contribution to the work in the included publications is clearly stated in the manuscript. Any part of this work has been submitted for award or degree at any other University.

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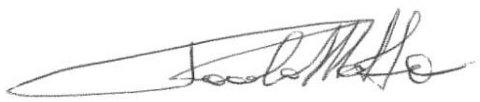

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Lay summary

In Cameroon, cattle are infected by a wide range of endemic and transboundary animal diseases (TADs) that hinder production and trade. A major driver of the dynamics of livestock, and zoonotic, infectious diseases is represented by animal movements. Livestock trade and seasonal transhumant migrations are the main determinants of cattle movements in Cameroon. Livestock markets are known to play an important role in the dispersal of infections in diverse farming systems. Seasonal transhumance is a widespread livestock management practice increasing the chances of coming into contact with geographically limited or seasonally abundant diseases.

Between September 2014 and May 2015 primary data were collected from the formal cattle trade system while a pilot study was conducted to investigate the informal seasonal transhumance. Multiple epidemiological and statistical methods were then used to characterise cattle movements in the country across different scales. The study of the cattle market system showed that the live cattle supply had consistent trends across the Regions of Cameroon over the year. The reduction in the trade volume during the dry season was accompanied by an opposite trend in the cattle price, that was consistently higher during the dry season.

The small variation in the structural characteristics of the cattle trade network and the consistency of trading connections between markets in Cameroon across the year, allowed key markets and Regions to be identified for targeted interventions. This information can be used to increase the surveillance sensitivity for multiple infectious diseases. Furthermore, the effectiveness of communication and awareness strategies for mitigation and control interventions can be improved by

targeting these key markets. This study is the first quantitative study of cattle trade in Cameroon and is an important contribution to creating a more evidence-based approach for the management of infectious diseases in the country. The improvement of the current data recording and management system in Cameroon could enable standardisation of key information on numbers, types of animals and prices that would then allow the analytical approaches developed in this work to be extended to improve surveillance and control of infectious diseases. Furthermore, the epidemiological and ecological contexts are expected to evolve under the rapid demographic, environmental and economic changes arising in the short-medium term. Therefore, there is a strong need for further quantitative analytical approaches based on empirical observations of the interactions between pathogens and the livestock production and trading systems to better inform epidemiological models aimed at improving cost-effectiveness of interventions benefiting animal health.

Thesis abstract

Introduction

In sub-Saharan Africa, rapid urbanisation and per capita consumption of animal source foods are expected to accelerate in the short-medium term and to increase the movements of live animals and animal products in the region. In Cameroon, where the livelihood of most of the rural population depends on the agricultural and livestock sector, a wide range of endemic transboundary infectious diseases (TADs) affect livestock production and trade, and have direct detrimental effects on animal, human and environmental health. Livestock mobility represents a central economic activity in the livestock value chain of the country as well as a central strategy of seasonal adaptation to the ecosystem. Livestock movements, however, are also a central driver of infectious diseases dynamics and contacts between livestock populations are major risk factors for disease introduction and circulation. In countries where financial and technical resources are constrained, such as Cameroon, strategic interventions aiming at the surveillance and control of multiple infectious diseases simultaneously are essential for optimising their cost-effectiveness. The overall aim of this study was to apply a methodological framework to contribute to the understanding of cattle movements in Cameroon and of their implications for disease circulation.

Methods

This project used a variety of epidemiological and statistical methods to characterise cattle movements in the country across different scales. The collection of primary data and information targeted both the formal cattle trade system, across the country, and the informal seasonal transhumance, across the main livestock production areas. Between September 2014 and May 2015 diverse strategies were applied for collecting empirical data and various data sources from multiple Regions of the country were combined. Cattle trade in Cameroon mainly occurs via multiple trading points owned and managed either by the veterinary authori-

ties or the municipalities. A total of 62 livestock markets, and the relevant offices of the Ministry of Livestock, Fisheries and Animal Products (MINEPIA), were targeted for collecting official data on cattle trade referring to a 12-month period ranging between September 2013 and August 2014. Additionally, a questionnaire-based survey with the various livestock markets stakeholders (herders, traders, butchers and veterinary officials) was carried out to collect a variety of information on the cattle market system. During this 9-month period of field work, data on cattle seasonal transhumance were simultaneously collected using a combination of GPS-tracking technology and questionnaire-based survey.

Results

Volumes of cattle trade, the type of traded animals and their commercial values varied over the year and across the Regions of the country included in this study. Nevertheless, the market supply of live cattle showed similar temporal trends over the year and across the Regions. Although for almost the entire study area the peak of traded animals in the market system was in December 2013, the trade volume was consistently higher during the rainy season (May to September). On the contrary, the reduction in the trade volume during the dry season was accompanied by an opposite trend in the cattle price, with their commercial value being higher during the dry season. Furthermore, a cattle price differential was highlighted between production Regions and high consumption Regions of the country.

The highest volume of cattle trade was recorded in the Adamawa Region, which was the main source of cattle for the country while also receiving animals from neighbouring countries, such as Chad and Central African Republic. In contrast, major urban markets in the Littoral and Central Regions were the main receivers of cattle originating from almost all the other areas of the country. Interestingly, the North-West Region appeared to be more independent and isolated within the cattle trade network of Cameroon, particularly receiving few animals from other Regions. Importantly, there was little variation in the structural characteristics of the cattle trade network as well as in its properties across seasons, showing that, despite the seasonality in traded numbers, the network of cattle moving between markets in Cameroon is very stable. This consistent structure of the network over the year increases the robustness of strategic targeted interventions. We found that targeting the top 20% of the most connected markets would significantly reduce the network cohesiveness providing opportunities for strategic disease surveillance, communication and risk mitigation interventions. The centrality of the market within the trading network was also found to be positively associated with the price of live cattle, which tended to be heavily affected by phenotypic characteristics of the traded cattle. The seasonal cattle transhumance has been found as a common and widespread practice for herders attending the market system across whole the study area, highlighting the close relation between formal trading movements and informal pastoral movements across the country. Transhumant herds were observed to undertake migrations across multiple Regions for period exceeding 6 months and showing the potential for multiple types of interactions with domestic and wild animals.

Discussion

Multiple livestock infectious diseases were identified as being related to the cattle trade system. As neighbouring and non-neighbouring countries were found to be epidemiologically connected it is clear that national strategies for surveillance and control are likely to have limited effectiveness. Regional coordination for designing and implementing prevention and mitigation strategies against infectious diseases is essential to improve animal health also at national level. This study highlights the opportunity for strategic surveillance, control and communication interventions targeting key livestock markets and Regions of Cameroon. Live cattle price and centrality of markets, represented by their connectedness within the trading network, highlights the need to further investigate the links between economic factors and drivers of disease dynamics, such as livestock movements. The complexity of cattle movements in this context was further evidenced by the seasonal transhumance representing an established common mechanism for managing livestock, and closely interacting with the formal trading system as well as with other domestic and wild animal populations. Better data collection and analysis of livestock movements is required for improving the effectiveness of surveillance and control of infectious diseases. Although animal identification and registration systems would represent an ideal step for increasing traceability of cattle movements, enhancing animal health management and the overall competitiveness of the livestock industry, in the short-term a cost-effective intervention should aim at further developing the current data recording and management systems. Pastoralism, for long seen as an economic and environmental activity with little future, also needs to be acknowledged as a key component of the livestock production system in the country and to be considered accordingly in the management of infectious diseases.

Acknowledgments

I am sure this is the hardest part of this thesis to write and I will force myself to keep it short. I am enormously grateful to all the persons that have accompanied me during this journey and I feel privileged because this project has really been an amazing journey in unique circumstances.

It is probably better to start with the most formal acknowledgement for the University of Edinburgh which funded my PhD through a Principal's Career Development Scholarship and to which I am very grateful. This was also possible thanks to Professor Mark Bronsvoort and Dr Ian Handel who trusted me after one single interview. Mark has been incredibly supportive since the beginning making available to me all his expertise and network for conceiving and implementing a research project really following our genuine common research interests. I remember Mark pushing me since the beginning, and all along, to constantly look for improvements and this is really a great example for the future and a reminder of how much I still have to learn. Ian has always been available to questions, discussions and data challenges never stopping having smart ideas and solutions to complex puzzles.

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Discovering Cameroon and the incredible variability of the cultures and contexts of this amazing country was a privilege, for which I mainly have to be grateful to Dr Vincent Tanya. While enabling the partnerships and national connections for realising this project, he and his wife Agatha have also treated me almost as a family member, including hosting and feeding me after some of the long and challenging missions in the field. During this period, I had the immense pleasure of studying the livestock system in the country under the unique guidance and friendship of Saidou Hamman, he is the ideal partner for field missions, particularly when unforeseen events are the routine.

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The entire EERA Group at The Roslin Institute created a wonderful and colourful atmosphere for learning and improving both technically and personally. Paul has been an incredible inspiration and a great support, and maybe more importantly a friend and a great football expert. I shamelessly bugged Gustaf and Stella with coding and any other sort of queries, for which they were always available and smiling. Adrian has been a friend all along and supported me in diverse moments. I also have very good memories of some conferences all together which will always bring good smiles. Dr Thibaud Porphyre was a great and friendly support since he first joined the EERA Group. He has always been available, even in the face of my enthusiasm, and I particularly need to thank him for his critical eye and patience. I have learned a lot also from you and enjoyed working with you. Meeting multiple times Professor Kenton Morgan is also something I will always be grateful, I never met nobody with such a natural and endless curiosity. I'm also very grateful to Dr Rob Christley for his availability and support in discussing the methodological approaches for key parts of this thesis.

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Last but by no means least, there's my family. Dad, I now know how much this PhD means also to you and I am grateful for your understanding. I've worked hard to get here but I wouldn't have made it without your support and example. Bill, this is also thanks to your support and your jokes along the way.

Publications and presentations

The following papers include work that has arisen from this thesis (published and submitted papers are in Appendix D):

- Motta, P., Porphyre, T., Handel, I., Hamman, S. M., Ngu Ngwa, V., Tanya, V., Morgan, K., Christley, R. and Bronsvoort, M. B. "*Implications of the cattle trade network in Cameroon for regional disease prevention and control*". Scientific Reports 7, 43932; doi: 10.1038/srep43932 (2017).

- Motta, P., Handel, I., Rydevik, G., Hamman, S. M., Ngu Ngwa, V., Tanya, V., Morgan, K., Bronsvoort, M. B. and Porphyre, T. "*Drivers of live cattle price in the livestock trading system of Central Cameroon*". Frontiers in Veterinary Science - Veterinary Epidemiology and Economics (under review).

- Motta, P., Porphyre, T., Hamman, S. M., Morgan, K., Ngu Ngwa, V., Tanya, V., Raizman, E., Handel, I. and Bronsvoort, M. B. "*Cattle transhumance and agropastoral nomadic herding practices in Central Cameroon*". Frontiers in Veterinary Science - Veterinary Epidemiology and Economics (under review).

Work from this thesis has been presented in the following conferences/meetings:

- Poster presentation at the Annual Meeting of the Society for Veterinary Epidemiology and Preventive Medicine - SVEPM (16-18 March 2016 in Elsinore, Denmark): "*Implications of cattle trade in Cameroon for infectious diseases regional circulation*"

- Oral presentation at the first Joint International Conference of the Association of Institutions for Tropical Veterinary Medicine (AITVM) and the Society of Tropical Veterinary Medicine (STVM) at the Humboldt University (4-8 September 2016 in Berlin, Germany): "*Implications of cattle trade in Cameroon for regional disease surveillance and control*"

- Oral presentation at the Inaugural Meeting of The International Society for Economics and Social Sciences of Animal Health (ISESSAH) (27-28 March 2017 in Aviemore, Scotland): "*Drivers of cattle market price formation in Cameroon*"

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List of abbreviations

BCV bovine coronavirus

BRSV bovine respiratory syncytial virus

bTB bovine tubercolosis

BVD bovine viral diarrhea

BVDV bovine viral diarrhea virus

CBPP contagious bovine pleuro-pneumonia

CC clustering coefficient

CFA Central African Franc (CFA) (currency)

CI confidence interval

CTS Cattle Tracing System

ECCAS Economic Community of Central African States

FAO Food and Agriculture Organisation of the United Nations

FMD foot and mouth disease

FMDV foot and mouth disease virus

GAM Generalised Additive Model

GAMM Generalised Additive Mixed Model

GDP Gross Domestic Product

GLM Generalised Linear Model

GNSS Global Satellite Navigation Systems

GPS Global Positioning System

GSCC Giant Strongly Connected Component

GSM Global System for Mobile Communications

GWCC Giant Weakly Connected Component

LSD lumpy skin disease

MINEPIA Cameroonian Ministry of Livestock, Fisheries, and Animal Industries

OIE World Organisation for Animal Health (Office International des Épizooties)

PL path length

PDR probability of disease ratio

R_0 basic reproduction number

R The R statistical environment and language

reR reachability ratio

RVF Rift Valley Fever

SIR Susceptible Infected Recovered Model

SMS Short Message Service

SNA social network analysis

SSA sub-Saharan Africa

UK United Kingdom

USD United States Dollar (currency)

WHO World Health Organisation

Chapter 1

General Introduction

1.1 Project Background

Veterinary public health management around the world is increasingly focusing towards more interdisciplinary approaches to minimise the health, social and economic impacts of both animal diseases and zoonotic infections. In 2004 the so called "Manhattan Principles" began the advocacy for an enhanced capacity for global human and animal health surveillance, for information-sharing among national and international institutions and for promoting a holistic "One Health" approach for preventing and controlling epidemic and endemic diseases (Arambulo [2011]). In accordance with these principles the Food and Agriculture Organization of the United Nations (FAO), the International World Organisation for Animal Health (OIE) and the World Health Organization (WHO) began a tripartite alliance to create a framework for safeguarding animal health, recognising its primary importance for the economic and social welfare, and for both food security and safety of nations and regions (WHO [2010]). This document recognises that prevention and early identification of emergence and spread of animal infectious diseases are a "global public good" with benefits extending to every country.

Demographic growth and economic development, with increasing urbanisation and social and cultural globalisation, are rising the demand for agricultural products and animal-source food. These factors, and the rapidly changing farming landscapes, are acting as central drivers for the growth of animal and animal products trade. Nevertheless, cultural, traditional and religious beliefs, as well as climatic and topographic factors are still important aspects influencing livestock mobility particularly in lower income countries (Todaro and Smith [2014]).

International trade, including of live animals and animal products, human mobility and other anthropogenic processes driven by globalisation, facilitate the transmission and establishment of emerging and re-emerging pathogens. The Sanitary and Phytosanitary Agreement of the World Trade Organization (www.wto.org [1994]) set the legal framework for trade in animals and animal products, allowing countries to decide and implement their own standards, based on scientific evidence, to the extent necessary to protect human, animal or plant health. These measures have a significant impact in countries where the standards of the veterinary services are poor and where national governments and smallholders are unable to sustain the investments required to satisfy these standards. Therefore, the ability to design and the opportunity to implement effective disease surveillance, prevention and control strategies are further technical barriers to access and compete in the international trade arena (Todaro and Smith [2014]). As a result, the presence of disease hinders the development of livestock sectors by lowering production efficiency and competitiveness, as well as by further precluding access to international markets.

Animal identification and traceability are key for establishing a reliable certification system enabling the enhancement of animal health, food safety and the overall competitiveness of the livestock industry. This framework becomes essential also for the management and early detection of diseases at their sources, and for strategic and targeted approaches to disease control. In particular, in countries where financial and technical resources and the institutional framework are constrained, targeted interventions are key to optimise resource utilisation. However, in pastoral settings and in contexts where the widespread unofficial and long distance livestock movements preclude strict national and international controls, the establishment of such identification and traceability systems are still very complex.

The risk of disseminating infectious diseases depends on the number and type of movements, on the volumes of animals moved, on the type of direct or indirect contact, on the prevalence of specific diseases among and between source and destination and on the pathogens ecology and transmission dynamics, including environmental factors. Generally, livestock trade-related movements occur via multiple intermediate steps in the form of a trading point, or market. Livestock markets, despite diverse levels of organisation and control, have been shown to play an important role in the dispersal of infectious diseases in diverse farming systems and in various regions of the world (Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Tempia et al. [2010]; Rautureau et al. [2011]; Dean et al. [2013]; Fournié and Pfeiffer [2013]; Vallée et al. [2013]; Molia et al. [2016]). Understanding trade routes and volumes and the risks associated with livestock trade movements is a key starting point for the creation of a favourable framework for animal health and the related risks management. This is also essential for strategic and targeted approaches to surveillance, emergency response and control of infectious diseases.

In settings where there is still restricted availability of information on animal movements and where official systems of animal identification, registration and traceability are not in place, formal studies of livestock movements are urgently needed. There is increasing demand for quantitative approaches and analysis based on empirical observations in order to understand the interactions between pathogens, the livestock production and trading systems and the wider environment, as well as to provide the baseline for more effective evidence-based decision making.

In sub-Saharan Africa (SSA) both trade-related and pastoral long distance and cross-border movements of livestock are common. One of the major livestock trading channels in this region is extending, in particular, through Chad, Central African Republic, Cameroon and Nigeria, where cattle trade represents a crucial activity for a significant proportion of the rural population (Bouslikhane [2015]). The first three countries of this list are also commonly interested by transhumance mobility, the cattle seasonal migration driven by the environmental constraints during the dry season (Dyer et al. [2008]). In Cameroon, the livestock sector represents a source of revenue to more than 30% of the rural population (Pamo [2008]), and cattle are the most widespread livestock with an estimated population of about 6.5 millions head (Ministry of Livestock, Fisheries, and Animal Industries - Cameroon [2012]). Understanding the dynamics of cattle movements across the country, identifying key areas and trading points, will help informing more strategic and targeted approaches to disease surveillance, prevention and control in the country. The structure of cattle mobility in Cameroon is complex and highly heterogeneous and very little knowledge of trade-related and pastoral movements is currently available for informing more cost-effective strategies.

1.2 Aim and Objectives of the project

The general aim of this project was to develop a methodological framework to contribute to improve the knowledge and the understanding of cattle movements in Cameroon, where the livestock sector is predominantly related to cattle production. The collection of primary data and information, their processing, analysis and interpretation aimed at studying the livestock market system, at capturing the patterns of cattle movements through the trading system and the seasonal transhumance and, ideally, at providing a baseline framework to contribute to the design and implementation of animal health interventions. Different studies were undertaken to fulfil a number of objectives.

The first objective was to characterise and study the cattle trade system, the main features of cattle markets and of animal management practices of the stakeholders involved in the system.

The second objective was to study the formal cattle movements through the cattle trading network identifying key markets for designing targeted communication, monitoring, surveillance and control interventions.

The third objective was to identify the main factors driving the formation of the price of live cattle in the Cameroon trading system and provide valuable information for future estimations of the impact of infectious diseases, and of potential control interventions in the country.

The final objective was to perform a feasibility study piloting the use of individual cattle Global Positioning System (GPS) tracking devices to uncover and investigate the informal livestock movements during the seasonal transhumance.

1.3 Thesis outline

The research conducted during this project will discuss the complexity of cattle movements in Cameroon and the implication for the management of livestock infectious diseases in the country. Diverse analytical approaches were applied to study the characteristics of cattle markets, the trading network, factors affecting cattle price and to present a pilot approach to investigate seasonal livestock movements.

Chapter 2 provides an introduction to the cattle movements in SSA presenting both a pastoral and commercial perspective and briefly discussing current challenges and constraints. This chapter provides a review of the current state of social network analysis (SNA) in the field of veterinary epidemiology discussing its applications for disease surveillance and control. A general introduction to Cameroon, its geographical and socio-economic aspects in relation to the livestock sector, and the known patterns of cattle movements, is also provided.

In Chapter 3 the methodological approaches for the collection of primary data, including an overall description of the study areas are presented and discussed. The various epidemiological and statistical methods to describe the cattle market system and characterise cattle movements across different scales in the country are presented and discussed at length.

Chapter 4 illustrates the descriptive analysis of the cattle trade system in Cameroon, describing volumes and commercial values of the traded cattle, providing an overview of the characteristics of the livestock markets and of the management practices of the various stakeholders involved in this system.

In Chapter 5 the focus is on the cattle trade network in Cameroon. Firstly, network analysis was used to describe the characteristics of the trade network and to identify key livestock markets. Secondly, the effectiveness of targeted and strategic interventions on the network was assessed for helping the prioritisation of resources allocation in the design and implementation of communication, surveillance and control strategies.

In Chapter 6 the factors affecting cattle price at the market level were investigated in the Adamawa and West Regions of Cameroon. The characteristics of the traded cattle and of the livestock markets, including their centrality in the trading network, as well as their relationship with human and cattle population in the areas under study were included in the analysis for assessing live cattle price formation.

In Chapter 7 the application of GPS-tracking technology were explored to study the seasonal cattle transhumance for the entire duration of the migration. The GPS data were used to estimate routes of migration and the general patterns of movements of cattle herds during these long distance migrations. More common data collection approaches were also used to describe relevant aspects for herds management during this seasonal migration.

Chapter 8 ends with a general critical assessment of the data, the methods and the findings of this thesis and a discussion on how this information could support the design and implementation of interventions for improving animal health management in the future.

Chapter 2

Literature Review

2.1 Background

In SSA livestock movement is a major strategy of adaptation to the ecosystem for nomadic populations, as well as representing an important economic activity for both the private and the public sector. However, livestock movement is also a key mechanism for the spread of animal diseases and zoonotic infections through both the traditional pastoral routes and the trade-related commercial channels.

In SSA, limited studies on livestock movements, and on trade-related movements in particular, have been recently carried out and, commonly, these studies focused primarily on socio-economic analysis (Scoones and Wolmer [2006]; Kamuanga et al. [2008]; Sikasso et al. [2006]; Mahmoud [2010]). In SSA, to date, only relatively few studies have explored the relevance and implications of livestock movements in relation to the epidemiology of infectious diseases (Di Nardo et al. [2011]; Dean et al. [2013]; Nicolas et al. [2013]; Vallée et al. [2013]; McCarron et al. [2015]; Lichoti et al. [2016]; Sintayehu et al. [2017]).

2.2 Pastoralism and transhumance in Africa

After the first domestication of cattle nearly 10,000 years ago in what is nowadays called the Middle East, cattle were introduced to Africa through the Eastern Sahara by migrating people as climatic change and aridness advanced (Decker et al. [2014]). Cattle herding then spread into the Central Sahara between 7,000 and 6,000 years ago, following a climatic change towards drier conditions (Brooks, Nick [2006]). As rainfall declined and became temporally and spatially more variable, livestock pastoralism enabled people and animals to adapt to the changing landscapes with reduced water and pasture resources. Since then pastoralism in Africa represents an adaptation strategy for human and livestock populations to the extremely variable environmental and ecological resources. Consequently, pastoralist communities are characterised historically and socially by their mobility, and their primary activity of rearing livestock (Dyer et al. [2008]). Traditionally, mobility has been the principal strategy pastoralists have used to cope with and manage their natural resources (Scoones and Wolmer [2006]). Nowadays, however, livestock movement is also becoming increasingly driven by trading and commercial factors (Bouslikhane [2015]).

Seasonal livestock movements, known as transhumance, are common across livestock production systems in SSA and are mainly driven by ecological and environmental constraints. Nonetheless, this seasonal and periodic transhumance can also be related to social and sanitary/animal health drivers, as well as to security and economic factors. In SSA transhumance is still an important coping strategy of pastoralist communities to weather major climatic crises and to harsh environment and conditions (Brooks, Nick [2006]). In general terms, two different forms of transhumance can be distinguished. A vertical transhumance, from winter pastures in the valleys to summer pastures in the mountains, and an horizontal transhumance, when migration occurs over similar altitudes (Behnke et al. [2011]). Generally, in the African continent two types of transhumance can be distinguished according to their scale and distances covered (Bouslikhane [2015]):

1. Short distance transhumance, aiming at optimizing land use between farming and rearing systems (e.g. exploiting crop residues);

2. Long-distance transhumance during the dry season, aiming at managing the seasonal variability of grazing for livestock populations (e.g. in response to seasonal rainfall patterns).

The main known pastoral flows of livestock movements between West and Central Africa are shown in Figure 2.1.

In many parts of Africa, transhumant pastoralists and sedentary farmers have engaged in symbiotic relations (Brooks, Nick [2006]). However, in the last few years, conflicts between pastoralist and farmers over competition for natural resources have intensified due to a combination of factors including worsening security, climate change, the expansion of cultivated areas and an increase in cattle herds (crisisgroup.org [2014]).

Both the risk of spreading animal and zoonotic diseases, and the potential generation of social tensions related with livestock movements, have led governments to seek to manage international and cross-border movements. Bilateral as well as regional and sub-regional agreements have tried to address the regulation of these movements. For instance, West African countries have set up a regional scheme to manage cross-border livestock movements between the fifteen member states the Economic Community of West African States (ECOWAS) issuing valid International Transhumance Certificates (ITC) within the ECOWAS community

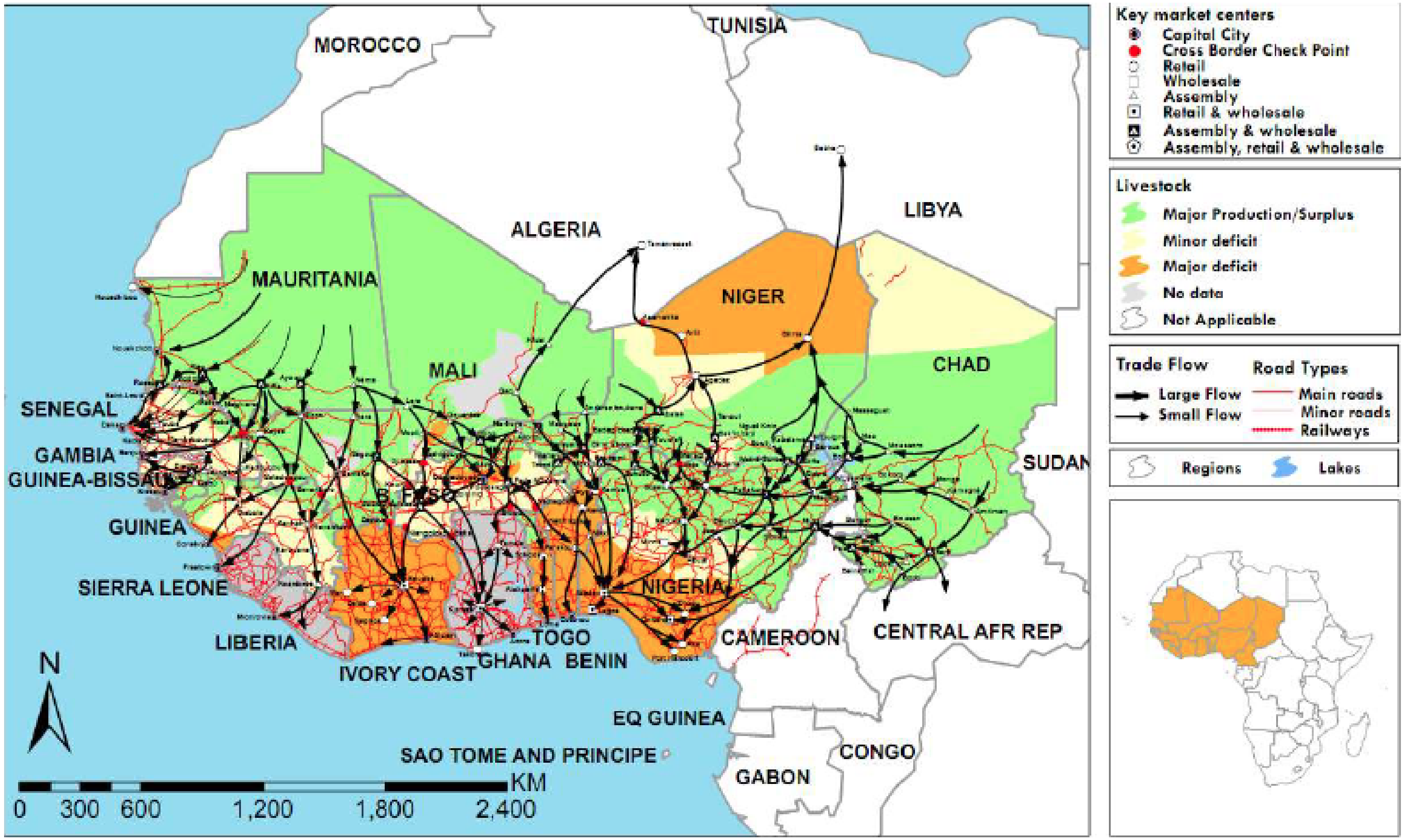

Figure 2.1: **Geography of regional livestock movements.**
This map shows the main livestock production and deficit zones in West Africa, along with the flows of livestock between these areas. While highlighting an overall flow of movements from East to West, it also shows a directed movement towards the South in West Africa and, contrary, northwards when moving more centrally in the continent (Source: Kamuanga et al. [2008]).

(Dyer et al. [2008]).

In Central Africa bilateral agreements are regulating international livestock movements between Chad and the Central African Republic, and Chad and Cameroon. In addition, transhumance between these and other countries in the region is also governed by a preliminary agreement through the regional economic organisation, the Economic Community of Central African States (ECCAS). In summary, the key points of this agreement are seeking to limit and discourage transhumance in the region not providing protection to pastoralists' access to land or water resources and prioritising the safeguard of the local farming communities (Dyer et al. [2008]).

For many decades pastoralism has been seen as an economic and environmental activity without a future. However, it is now starting to be acknowledged as an important component for economic development in the African continent and key to achieve the projected growth in livestock sectors (Bonnet and Bertrand [2012]). Pastoralism constitutes a rational use of drylands and is proving useful in restoring and maintaining the ecological balance in increasingly drier areas (Gerber et al. [2013]; Nassef et al. [2009]). In the progressively alarming context of global climate change the ecological active role of pastoralism also further supports its potential for improving management of greenhouse gasses emissions, particularly when compared to intensive livestock systems (Hamro-Drotz et al. [2011]). Mobile pastoral systems of production and management, therefore, represent a viable component for market development, necessary to satisfy the expected demographic growth and the increased demand for animal products (Nassef et al. [2009]).

2.3 Overview of livestock trade in SSA

The trading routes in SSA are economically driven but they also relate to traditional and environmental factors, as there is a profound interconnection between these drivers. A number of animal and animal product trading routes have been described in Africa (Bouslikhane [2015]).

The major commercial trade routes across the whole continent are:

1. The Central African route, exporting live animals from the Sahel to be slaughtered for human consumption in equatorial forest countries where livestock production is very limited;

2. The Horn of Africa route, exporting live animals to the Gulf States and Middle East countries for slaughter for human consumption to supply the large wealthy populations;

3. The East Africa route, exporting live animals and dairy products between countries in the Great Lakes region;

4. The Indian Ocean route, exporting mainly animal products from Botswana and South Africa to Europe;

5. The North Africa route trading live small ruminants and camelids from the Sahel to countries of North Africa;

6. The West African routes for the export of live cattle and small ruminants from the Sahel to coastal countries: (a) the "central corridor" from Mali and Burkina Faso to supply Cote d'Ivoire, Ghana, Togo and Benin, (b) the "first western route" from Mauritania and Mali to Cote d'Ivoire, Senegal, Gambia and Guinea Bissau and (c) the "second western route" from Chad, Niger, Sudan, Central African Republic, Mali and Burkina Faso to supply

Cameroon, Nigeria, Benin and Togo.

All these commercial routes create a vast and complex network of national and cross-border livestock trading movements. There are a number of factors that impact and affect these movements and, consequently, the development of the livestock sector and are listed in the Section 2.3.1 and 2.3.2.

2.3.1 Non-sanitary constraints

Socio-economic stability of communities and countries can be undermined by, among other factors, political uncertainty, conflicts, social inequality and insecurity, particularly when these situations are compounded by natural disasters or human and animal diseases. One of the continent's most destructive natural hazards are droughts, which can trigger a cascade of consequences including livestock and human mobilisation. A recent example are the harsh droughts in the Horn of Africa in 2011 and currently in 2017 causing a range of consequences from impoverishment of pastures and destabilisation of markets, up to the displacements of both animal and human populations for their survival.

Institutional constraints to animal movements include the poor level of organisation of public operators in the livestock sector and the inadequacy of the infrastructures (transport networks, livestock markets, abattoirs, etc.). The lack of, or the weak implementation of, regional coordination increases transaction costs resulting from uncoordinated legislation and policies. Additionally, "hidden" or "informal" costs imposed at various stages of the livestock marketing channels are another common obstacle for the development of intra-African trade (Todaro and Smith [2014]; Bouslikhane [2015]).

2.3.2 Sanitary constraints

Sanitary constraints are also affecting legal movements of live animals, and animal products. Most livestock producing countries in SSA are unable to properly establish themselves in the global market also due to their current inability to meet international sanitary requirements. The standards for the control of animal diseases and for trade in livestock and livestock products are stated under the World Trade Organization (WTO) Sanitary and Phyto-sanitary (SPS) Agreement (www.wto.org [1994]). These standards for the control of animal diseases, generally, do not allow for international official movements of livestock from countries where certain diseases are endemic toward countries considered to be free from these diseases. This regulation has an obvious impact on shaping the direction of trading connections and, therefore, of movements of livestock and their products.

Transboundary animal diseases (TADs) are the major constraints for legal international movements of live animals. TADs are contagious epidemic pathogens that can spread extremely rapidly, irrespective of national borders, and that can have significant socio-economic, trade and/or food security impacts for a considerable number of countries (Lubroth and De Balogh [2009]). For large livestock, the currently most significant TADs in SSA are foot and mouth disease (FMD), contagious bovine pleuropneumonia (CBPP), Rift Valley fever (RVF), hemorrhagic septicaemia (HS), lumpy skin disease (LSD), peste des petits ruminants (PPR) and sheep pox and goat pox (SPV and GPV). Historically, before its global eradication, Rinderpest was also endemic in the pastoral lands across SSA. African swine fever (ASF) in pigs as well as Avian Influenza (AI) and Newcastle disease (ND) in avian species, are also particularly relevant TADs across the continent (Otte and Mcleod [2004]).

In Section 2.16.4 TADs and other endemic diseases affecting the livestock population in Cameroon are introduced and discussed more specifically.

2.4 Livestock price and contributing factors

Trade of live animals and livestock products represents a major component of the agricultural sector in SSA (Todaro and Smith [2014]). Importantly, the sale of livestock is also a key cash generating mechanism (Little et al. [2001]) that allows purchasing food and family necessities for a large proportion of the rural households in SSA (Thornton [2002]; Todaro and Smith [2014]). Livestock value, therefore, represents a key asset for reducing the vulnerability of rural households to a number of external factors, such as climate change, animal diseases and social and political instability.

Studies in other regions of the world, notably in Northern and Southern America, have shown that a number of factors affect the price of livestock, such as physical, genetic and nutritional characteristics, as well as handling and market conditions (Troxel and Barham [2007]; Christofari et al. [2010]; Koetz Júnior et al. [2014]). In these intensive and semi-intensive cattle rearing systems animal price tends to be affected by muscle scores, weights, diet as well as breed for an example (Christofari et al. [2010]; Koetz Júnior et al. [2014]). Studies in SSA, on the contrary, have focused primarily on understanding price variation over time, in particular assessing how price respond to environmental and ecological variability, such as droughts and pasture availability, and to shifts in export and meat demand (Fafchamps and Gavian [1997]).

The lack of a reliable price information system is a common constraint on livestock marketing both in the pastoral and urban areas across most SSA (Pavanello

[2010]; Onono et al. [2015]). Sanitary constraints and animal diseases, in particular, generate a wide range of direct and indirect socio-economic impacts on rural households in the region (Thornton [2010]). Difficulties in assessing and measuring these impacts in SSA are often caused by the lack of relevant data on livestock values and their adequate understanding and application (Perry et al. [2013]). Therefore, for estimating the impact of infectious diseases both in terms of direct and indirect losses at local and national level, knowledge of livestock value and understanding of drivers of price formation are essential (Knight-Jones and Rushton [2013]). Similarly, the inadequacy of this information limits the assessments of the costs of alternative available control strategies for infectious diseases (Bradbury et al. [2017]), particularly required in contexts with very limited resources and higher needs for cost-effective interventions for animal health management.

2.5 Key challenges for livestock diseases control in SSA

In SSA the formal and informal movements of animals coexist at local, national and regional levels. Livestock movements are a central driver of disease dynamics and can result in the dissemination of endemic diseases, or in the introduction and spread of exotic animal diseases (Fèvre et al. [2006]). The risk of introducing and disseminating infectious diseases across countries depends on animal movements as well as on a combination of other multiple factors. Pathogen ecology and transmission dynamics are key factors in the epidemiology of various infectious diseases. In particular for vector-borne diseases, such as Trypanosomiasis and Rift Valley Fever (RFV) for instance, and for diseases where reservoirs or carrier hosts, in domestic and wildlife populations, may play an important role, as for ASF or AI. Disease prevalence among and between areas and regions is clearly another central factor particularly for pathogens that can rapidly spread via livestock movements through direct or indirect contacts, such as FMD, PPR and SPV and GPV.

Nomadic livestock husbandry practices, combined with the permeability of borders to legal or illegal movements and the limited capacity of veterinary surveillance systems are major challenges for prevention and control of rapidly spreading TADs in particular (Bouslikhane [2015]). Critical aspects impacting the development and implementation of systems for traceability and management of animal movements in the region are represented by the current inadequate knowledge of these movements and the inadequate capacities and resources of the animal health services (Edwards [2006]).

Limitations for disease control in the region, are related also to the current diagnostic and intervention capacities to face outbreaks and epidemics at a national and international level. Adequate laboratory infrastructures and rapid diagnostic tools are still mostly lacking, increasing the time of detection and confirmation of outbreaks (Edwards [2006]). The current challenges and delays in detection, confirmation and response hinder the effective control of livestock, and zoonotic, diseases.

Innovative disease passive surveillance strategies such as informal reporting through local press, word of mouth and use of social media, are slowly taking off. Freedom of internet accessibility is still a challenge faced in the region, as testified by the internet ban implemented in parts of Cameroon during the first quarter of 2017 (BBC - News [2017]).

Another critical obstacle is represented by the design and implementation of vaccination strategies for prevention and control programs. Effective vaccination strategies require a clear understanding of the epidemiology of the target disease in the population of interest (and subpopulations) and of the risks factors related for its control (such as animal movements). Another critical obstacle is represented by the effective availability and delivery of vaccines and their actual efficacy. Vaccine formulation is a key aspect, particularly for rapidly evolving pathogens, such as FMDV, and vaccine effectiveness is paramount for the success of vaccination campaigns. Similarly, the efficient delivery and the effective maintenance of the cold chain for the correct storage of vaccines are critical for the success of vaccination strategies for infectious diseases management. All these factors, in combination, contribute to the current low preparedness to face and manage the circulation and control of many animal and zoonotic infectious diseases in the region (Edwards [2006]).

2.6 Examples of livestock registration and traceability systems across the world

Livestock identification and traceability systems are a fundamental tool for animal health management, including for the design and implementation of surveillance and control strategies. The planning and management of such systems are a major component of national disease surveillance and control programmes in a number of countries as well as a basic requirement to allow international trade. Such systems are also fundamental in providing the means for a rapid and more effective response in case of a disease outbreak, as well as in providing data and information to enable research and surveillance efforts.

In the mid-90s during the aftermath of the bovine spongiform encephalopathy

(BSE) crisis in the United Kingdom (UK), the European Union (EU) was the first authority introducing guidelines and standards for livestock traceability systems. In 1997 the Council Regulation (EC) No 820/97 was the first step of this strategy, which was then refined by the Council Regulations (EC) No 1760/2000 and (EC) No 1825/2012. In summary these regulations require all European Member States to establish a system for the individual identification of live animals, the maintenance of computerised databases recording demographic and movement data, the introduction of animal passports from birth to death for each animal and of individual registers for each holding as a permanent and updated record of potentially infectious contacts.

Since then a number of countries, in other continents, have implemented animal tracing systems including North and South America, Oceania, Asia and Africa. The databases developed as a result of the implementation of these systems are an invaluable source of data to study the movements of livestock and eventually the spread of infectious diseases at a national level as occurred following the 2001 FMD outbreak in the United Kingdom (UK) (Christley et al. [2005]; Kiss et al. [2006]; Ortiz-Pelaez et al. [2006]). However, in SSA, where the livestock sector has a more extensive organisation and where formal systems for identification and traceability are often not implemented, the knowledge of livestock movements is still poor. One of the greatest limitation to understanding livestock movements is the lack of recent data on movements due to the lack of compliance with the international recommendations.

2.7 An introduction of network analysis in veterinary epidemiology

In an increasing number of countries, the implementation of animal tracing systems, has generated an unprecedented amount of data to study livestock movements and eventually the spread of infectious diseases, as in the case of the British Cattle Tracing System (CTS) (Christley et al. [2005]; Kiss et al. [2006]; Ortiz-Pelaez et al. [2006]). These relational data enable the researcher to characterise the nature and the structure of livestock social interactions and the potential for disease spread.

A number of different approaches are currently available to study movement and relational data in order to characterise the nature and the structure of social interactions. Network analysis provides a formal framework for understanding relational systems in several fields of science such as physics, chemistry, biology, economics and sociology (Barabási and Albert [1999]; Barabási and Bonabeau [2003]). One of the main strengths of the network approach is that it provides a common framework for the characterisation of social and relational systems at different organisational levels, ranging from individuals to populations. In addition, network theory represents a statistical analysis technique that provides a number of novel descriptors of the properties of individuals, groups or populations (James et al. [2009]). It offers the theoretical framework for the study of the characteristics and properties of networks. This approach allows measuring the patterns of contacts, identifying important constituents of the networks and describing the features of its components (James et al. [2009]).

Despite being firstly established in physics, the social sciences and other science fields, social network analysis (SNA) has only relatively recently been applied to the animal sciences. It is progressively utilised in the description of the social structure of animal populations in behavioural ecology (Drewe et al. [2012]; Ryder et al. [2012]). Network analysis is also applied in veterinary epidemiology, providing useful insights on disease dynamics and showing its potential for identifying critical transmission points within the animal movement pathway in various settings (Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Dubé et al. [2010]; Smith et al. [2013]). Knowledge of network topology is increasingly proving to be instrumental in many applications in veterinary epidemiology, particularly for diseases where direct and indirect live animal movements and contacts constitute a major risk of introduction and dissemination of infectious diseases. Network analysis is also now showing its potential for improving current disease surveillance and prevention systems, providing important information to increase the sensitivity of risk-based surveillance (Hardstaff et al. [2015]; Schärrer et al. [2015]).

2.8 Livestock traceability and network analysis in veterinary epidemiology in SSA

Livestock identification and tracing systems are key for improving animal health, through better disease control, and consumer protection, through increased food safety standards. However, in the vast majority of African countries, where social and cultural aspects are an additional complexity for their implementation, such systems are not yet in place. Exceptions in the continent are represented by most of the Maghreb countries (Morocco, Algeria and Tunisia), Botswana, Republic of South Africa and Namibia where animal identification and tracing systems have been implemented countrywide or in specific regions.

The lack of such systems still creates a vacuum where accurate census data and information on livestock movements are not available for their appropriate study and to better investigate the dynamics of infectious diseases for designing surveillance and control strategies. In this context informing targeted interventions become even more vital in order to maximise the resource utilisation and optimise their impact. Despite this paucity of data across the continent, network analysis has been recently applied to study movements of different livestock species (Dean et al. [2013]; Nicolas et al. [2013]; Vallée et al. [2013]; McCarron et al. [2015]; Lichoti et al. [2016]; Sintayehu et al. [2017]). Nevertheless, due to the scarcity of available information on livestock movements in SSA, and to the difficulties to access them, all of these studies could rely only on questionnaire-based surveys to capture the dynamics of livestock movements networks. Additionally, because of the complexity of generalising information for broader regions from surveys in limited areas, most of these studies refer only to specific regions or districts within the country of interest.

The study from Dean et al. [2013], to our knowledge, was the first example of using questionnaire-based surveys to simulate real animal flows at a broader scale and across multiple countries in SSA. This research is also one of the very few studies that have applied SNA on cattle movements in SSA highlighting potential risks for regional disease spread through cross-border cattle trade. Social network analysis was also applied to study cattle movements in the Madagascar highlands and explore implications of this movements for the spread of RFV at the local level (Nicolas et al. [2013]). This study highlighted a statistical association between network centrality parameters and occurrence of seroconversion in cattle populations of different villages of a local contact network (Nicolas et al. [2013]). More recently, another study applying network analysis techniques on cattle movements in the Afar Region of Ethiopia by Sintayehu et al. [2017], highlighted a positive association of herd's connectivity, and their centrality in the cattle transfer network, with the presence of bTB infection within the herd. Nevertheless, unfortunately, any of these recent studies could use official recorded information to analyse livestock movements and to apply SNA at a national scale and these results could refer only to limited areas.

2.9 Introduction to network theory

2.9.1 Scale-free networks

For many decades the study of infectious diseases has assumed that infectious contacts occurred between random individuals within a population. In the early 90's attempts to simulate the diffusion of sexually-transmitted human infectious diseases using epidemiological modeling, led to the observation that few individuals in the human population presented uncommonly high sexual contact rates and were responsible for driving these epidemics (Barbour and Mollison [1990]). Further studies on the ecology of infectious diseases highlighted that often, 20% of the host population is responsible for 80% of the transmission of infectious agents (Woolhouse et al. [1997]).

The more recent application of SNA in epidemiology has led to the study of different types of networks with regard to the spread of infectious agents (Keeling and Eames [2005]). As in most of the complex networks observed in several fields of science, the heterogeneity of the contact structure also emerged as a common feature in epidemiology (Barabási and Bonabeau [2003]; Christley et al. [2005]). Most real-world networks follow a so-called power-law distribution, described by a continuously decreasing function of the connections between the units of interest, resulting in a highly right-skewed curve (Barabási and Albert [1999]). This curve represents the tendency of networks to present few units holding most of the connections of the entire network while, vice versa, most units display only few connections. This characteristic is peculiar of the so-called scale-free networks.

Scale-free networks present two other specific characteristics: the tendency of the *epidemic threshold* towards zero (Pastor-Satorras and Vespignani [2001]) and the so-called preferential attachment (Barabási and Bonabeau [2003]); Barabási [2009]). According to the latter principle, new constituents of a network tend to connect to the ones that exhibit a higher number of contacts, leading to the natural emergence of highly connected nodes, defined as hubs, and therefore contributing to the heterogeneity of the network (Barabási and Bonabeau [2003]).

In epidemiology the average number of secondary infections produced by the introduction of a single infected host in an entirely susceptible population is defined as the *basic reproductive rate* or R_0 (Dohoo et al. [2012]). The *epidemic threshold* is defined as a critical value of the R_0 at which epidemics become possible in a population and, generally, a threshold value equal or above one is considered to be necessary for the disease to be maintained and to spread within the population (Dohoo et al. [2012]). The R_0 and, therefore, the *epidemic threshold* depend on transmission and recovery rates of a disease, as well as on the structure of the population (Volz and Meyers [2009]). Pastor-Satorras and Vespignani [2001] observed that in scale-free networks, where few units are highly connected and the majority of the units are sparsely connected, the *epidemic threshold* tends to zero. This low threshold implies that scale-free networks are prone to the persistence and the spreading of infectious agents explicitly because of the heterogeneity of the contact structure, and that the transmission rate of the specific agent in these populations also depend on the contact structure (Volz and Meyers [2009]). This heterogeneity in the contact structure, while facilitating the maintenance and the spread of a disease, also renders a resident strain more resilient to invasion by new variants, therefore, potentially slowing disease adaptation and evolution in more isolated areas of networks (Leventhal et al. [2015]).

These characteristics of the scale-free networks explain the particular resiliency of these systems to control measures if randomly applied to the network (Barabási and Bonabeau [2003]; Dubé et al. [2011]). Conversely, in these types of networks, targeted interventions may become extremely efficient in increasing the impact of approaches as, for instance, contact-reducing and immunising strategies (Keeling and Eames [2005]; Ancel Meyers [2007]; Frössling et al. [2012]; Frössling et al. [2014]; Hardstaff et al. [2015]; Schärrer et al. [2015]).

Following these theoretical findings, Lloyd-Smith et al. [2005] proposed that "super-spreading events", during which certain individuals infect unusually large numbers of secondary cases, might play a central role in epidemics. According to these authors "super-spreading events" are due to a combination of three broad factors: individual variation in infectiousness and susceptibility to infection, individual variation in contact rates, and the environmental context. The study of the epidemiology of the severe acute respiratory syndrome (SARS) revealed the critical role played by specific events, such as church gatherings or fraternity meetings, and particular locations, such as airports and harbours (Lloyd-Smith et al. [2005]). Following these findings it is reasonable to understand that if a pathogen reaches a hub in the network, as occurred in the auction markets during the 2001 FMD outbreak in the UK, this will affect both the size and the velocity of an epidemic, with a large number of other nodes becoming infected in a short time period (Christley et al. [2005]; Kiss et al. [2006]).

2.9.2 Small-world properties

In addition to the heterogeneity of the contact structure, another characteristic of networks with key implications also in the epidemiology of infectious diseases is that most of the components of the network are not directly connected to each other but can be reached through a small number of steps. This organisational structure of the network tends to lead to the creation of local clusters of nodes. When this local clustering coexists with long distance connections across the network, a so-called small-world behaviour is observed (Shirley and Rushton [2005]; Lockhart et al. [2010]; Dubé et al. [2011]). This small-world behavior is of particular interest in biology and epidemiology as small worlds may facilitate the rapid diffusion of socially transmitted infections across the network (James et al. [2009]).

An important implication of small-world networks is that an infection cannot only spread within clusters, but may also reach distant sub-regions in the network. In this context it becomes clear that large geographical distances may not represent a barrier to the dissemination of infectious diseases (Lockhart et al. [2010]; Dubé et al. [2011]; Smith et al. [2013]). Hence, identification and characterisation of these long distance interactions will offer the opportunity for an "intelligent tracing", applying empirical knowledge in infectious disease surveillance and prevention through the control of these interactions in order to reduce the likelihood of epidemic dissemination (Kiss et al. [2006]; Dubé et al. [2010]; Rautureau et al. [2011]; Frössling et al. [2012]; Frössling et al. [2014]; Gates and Woolhouse [2015])

2.9.3 Network terminology

Graph theory provides the theoretical and analytical framework for the study of the characteristics and properties of networks. Networks are defined as an assortment of units of interest that may or may not be connected to each other (Martínez-López et al. [2009]). These units of interest are referred to as nodes, or vertices, and can be linked through various types of relationships. In livestock movement networks, the unit of concern could be defined as, for instance, a livestock holding (market or farm) or in some situations even a geographic area such as an administrative district or a village. This unit of interest might present attributes, such as species, number of animals or size of the holding. The connections between units might present attributes as well, as the weighting that can be given to the links by the number of animals moving through this connection. The time period during which the movements between units occur is another critical aspect. Generally, the time window considered has implications for the disease under study. For instance, rapidly spreading diseases, such as FMD, are studied considering short time windows for the spread of the infection over social networks (Dubé et al. [2008]; Nöremark et al. [2011]). Longer time windows are more appropriate for the study of diseases with a lower spreading ability, such as chronic diseases (Sonneveld et al. [2009]; Nicolas et al. [2013]).

A pair of connected nodes is defined as a *dyad* and a triple as a *triad*. When these connections are reciprocal or bidirectional, such as 2-way contact between two markets, they are defined as *edges* and the network as *undirected*. Conversely *directed* networks describe unidirectional relationships or links, referred to as *arcs*, such as for instance the unidirectional movement of one animal from an origin market to a destination market. Generally, contacts between livestock premises occur through directed networks from a source location to a recipient site (Dubé et al. [2010]). However, vehicles and fomites can potentially represent a source of bi-directional contact, acting, hence, as an undirected network. This behaviour can become even more common in contexts and countries where animal movement is less regulated and where livestock is more mobile both among various types of premises and across regions.

A *path* is a sequence of adjacent *edges* or *arcs* that are linking nodes. These can be connected to one another directly as well as indirectly, through intermediaries. The *path length* is, therefore, defined as the number of steps between any given pair of nodes in the network. At a network level the average distance in number of steps to reach any given node from any other node in the network is used to determine the *average path length*.

2.9.4 Measures of centrality: node-level metrics

The term "centrality" refers to the extension of the relationships of one node with other units of interest and, hence, its "importance" in the network. Therefore, in livestock movement networks, node-level measures are important to assess the role of the various holdings. The number of direct contacts per unit of interest determines the node *degree*. While in an *undirected* network the node *degree* would represent the number of nodes with which a node shares a connection, in directed networks it can be further partitioned into *in-degree* and *out-degree*. *In-degree* is equal to the number of connections that each node receives and, therefore, in a livestock network, for instance, is equivalent to the potential sources of infection. Conversely, *out-degree* indicates the number of connections that originate from each node, and consequently the number of potential units to which the infection can be transmitted.

Neighbourhood size relates to the node *degree*, and indicates the number of nodes that can be reached within a specific amount of inward and outward steps from a node of interest. As already discussed, the *path length* is the topological distance (number fo steps between nodes) and differs from the geographical distance. Therefore, the *farness* is a measure that expresses how far nodes are topologically in the system and, conversely, the *closeness* measures how close a specific node is to the other nodes in terms of number of steps.

The frequency with which a node is located on the shortest path length between any pair of nodes is defined as the *betweenness* of a node. A high *betweenness* of a node relates to its capacity to link a large number of pairs, which would be otherwise unconnected and, therefore, represents an important indication of the central role of a node. For instance, livestock markets have been found to have high *betweenness* in both the UK sheep and cattle movement networks and, therefore, being a central component of these networks (Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]). Another centrality index is the *eigenvector centrality.* This measure is related to the centrality of the nodes to which the node of interest is connected to, and to the strength of these connections. In social networks it can be defined as a "measure of popularity", assuming that connections to central nodes are more important than equivalent connections to more peripheral nodes.

In livestock movement networks node-level metrics are, therefore, important to assess the role of various nodes, such as livestock holdings or markets. Nevertheless, there is constant debate on which centrality measure performs best for this purpose. Natale et al. [2009], in a simulation study on the Italian cattle network over an entire year cycle, showed that targeting and isolating of as few as 1% of the total nodes, based on the node *degree*, resulted in an 88% reduction in the number of infected nodes. Alternatively, if this intervention was based on the *betweenness* it resulted in a 66% reduction. With a similar approach the French cattle movements network from 2005 to 2009 was analysed at different temporal windows by Dutta et al. [2014]. This study showed that targeting the nodes with the highest *betweenness* was an efficient strategy to reduce the connectedness of the network also when relying only on historical data from past years of observation. This year to year consistency of cattle movements networks and of their centrality metrics was also reported in between-farm cattle movement in Uruguay by VanderWaal et al. [2016] and in New Zealand by Marquetoux et al. [2016].

2.9.5 Measures of cohesiveness: network-level metrics

The assessment of the cohesiveness of the whole network may provide important information for the identification of structural weaknesses of the network. Nodes and connections that, if eliminated, may lead to the fragmentation of the network into unconnected sub-sets are defined, respectively, as *cut-points* and *bridges*. These concepts may reflect important applications in infectious disease management, helping identifying more efficient strategies for the prevention and control of the spread of infectious diseases, as described by Robinson and Christley (Robinson and Christley [2007]). Examining the network of cattle movements through auction markets in the UK between 2002 and 2004, these authors identified markets and farms with high *betweenness* as acting as *cut-points*, for the overall connectedness of the network.

An important measure of cohesiveness is the *density* of a network. It is defined as the value of the proportion of observed contacts between nodes, out of all the possible contacts in the network. A closely related measure is the *fragmentation* *index*, which represents the proportion of pairs of nodes in the network that are not connected to each other.

Another key measure is given by the overall probability that any two immediate neighbours of a node, so directly connected to this node, are also directly connected to each other, and is defined by the value of the *clustering coefficient*. Interestingly, a high *clustering coefficient* together with a short *average path length*, represent a typical behaviour of small-world networks, characterised by a few long distance connections that link clusters or subgroups of nodes, topologically distant in the network (Dubé et al. [2011]).

Assortative mixing is a property observed in many social networks according to which many nodes with high *degree* tend to connect to other highly connected nodes. Conversely, many technological and biological networks show a disassortative mixing behaviour, where hubs tend to connect to nodes with low *degree* . *Assortative mixing*, when highly connected nodes tend to link to nodes with similar properties, has been related to an increased rapidity of disease spread compared to *disassortative mixing*, when highly connected nodes tend to link to isolated nodes (Kiss et al. [2008]).

2.10 Estimation of the resilience and vulnerability of networks

Combining the measures of node centrality and network cohesiveness can provide more comprehensive information of networks structure, as well as of their vulnerability to targeted interventions. Cohesive sub-group analysis provides the framework for the identification of maximally connected sub-groups of nodes, or sub-graphs, within the network. Several network cluster algorithms have been developed in SNA for this purpose, however there is not a single universal approach. There are two general strategies to identify cohesive subgroups: a bottom-up and a top-down approach. In the first case the analysis starts from small-connected units (*clique*) and proceeds by aggregating the closest units. Conversely the top-down approach begins from the entire network structure and, identifying the vulnerable points, aims at partitioning the network into more densely connected parts. A *clique* is defined as a maximally complete subgroup including three or more nodes, in which any node is connected to any other. Therefore, different *cliques* can overlap and nodes can be embedded in different *cliques*. The bottom-up approach groups together nodes sharing a large number of common *cliques* until all nodes end up being in the same cluster.

The top-down approach aims at identifying components or block structures. Components are defined as maximally connected sub-regions of a network in which all pairs of nodes are directly or indirectly connected. Therefore, in an *undirected* network, all mutually reachable nodes are part of a component. Conversely, in a *directed* network all the nodes that are mutually accessible, accounting for the direction of the link, form a strong component, whereas those that are mutually accessible not accounting for the direction of the connections are part of a weak component. The sizes of the biggest strong and weak component have been, therefore, used in the estimation of the maximal size of the population at risk in case of an epidemic in several studies (Kiss et al. [2006]; Kiss et al. [2008]; Dean et al. [2013]).

The top-down approach also includes the study of factions and core-periphery structures. The factions analysis aims to examine to what extent a network is close to an ideal structure where each node is connected to all others in their own sub-graph (faction). The core-periphery technique aims at examining to what extent a network is close to a two-group structure where the first group is composed of central nodes (core) all connected to each other, and the second group is composed of marginal nodes (periphery), which are not connected to each other but can be connected to the core.

Among both bottom-up and top-down approaches the identification of the components of nodes is the most widely used in network epidemiology. The strong and weak components size are also commonly applied in the estimation of the size of the population at risk in the case of an epidemic. In particular the *giant strongly connected component* (*GSCC*) is defined as the largest subset of nodes that are mutually reachable through directed paths. Therefore, if an infectious agent is introduced in a node within the *GSCC* of a livestock holdings network it will have the potential to directly spread to all other premises within the *GSCC* (Kao et al. [2006]; Kiss et al. [2006]; Volkova et al. [2010]). Consequently, this measure has been proposed to estimate the lower bound of the maximum epidemic size. Conversely, the largest subgroup of accessible nodes through any contact despite the direction of the contact, the (*giant weakly connected component*) (*GWCC*), has been proposed as the estimate for the upper bound of the epidemic size (Kao et al. [2006]; Kenah and Robins [2007]; Volkova et al. [2010]).

In a *directed* network, connections between nodes of a strong component, mutually accessible accounting for the direction of the links, may lead back to that initial node. However, this is not necessarily always the case for livestock networks. The relationship between premises are not always reciprocal, as required by the definition of strong components. Consequently, the suitability of *GSCC* and *GWCC* for the estimation of the potential epidemic size must be evaluated accordingly to the specific context, the topology and the connectivity of the network under scrutiny. In an attempt to overcome some of these shortcomings (Dubé et al. [2008]; Dubé et al. [2011]) proposed an alternative measure for the estimation of the potential epidemic size, accounting for the direction of the connections and the temporal order in which these are occurring. This metric, referred to as *infection chain*, originates from the field of social science and can be expressed as the number of nodes (e.g. farms/markets) that can be reached directly or indirectly through another node, within a specific time period, regardless of the topological position in the network. This measure has then been further refined into *outgoing infection chain* and *ingoing infection chain* by Nöremark et al. [2011].

The *infection chain* approach has been shown to provide accurate estimates of the maximal epidemic size in the presence of highly fragmented networks. This was particularly the case for the networks of dairy cattle movements in Canada (Dubé et al. [2008]) and cattle and pig movements in Sweden (Nöremark et al. [2011]), as well as in highly directed networks as commonly found in the fish industry (Green et al. [2009]).

2.11 Temporally dynamic networks

The temporal dimension characterises the structural evolution of a network. In the case of livestock trade connections between farms and markets, in particular, these links are, usually, in place only at the time of the transport. Chronology of contacts is key in tracing the spread of infectious diseases as the temporal sequence of trade contacts forms a chain of transmission. Therefore, given the dynamic architecture of networks, traditional static network measures can hide important structural changes affecting the nodes or links transmission potential, particularly during outbreaks, limiting the efficacy of interventions.

Several attempts have been undertaken during the recent past to understand and describe the structural evolution of networks and to develop measures of centrality accounting for the evolution of networks overtime. Ancel Meyers [2007] derived two network statistics: the *mean original degree* of the network at base time, and the *mean residual degree* of the nodes remaining in the residual network after a specific time period. The residual degree after an epidemic is obtained by dividing the network into the nodes that become infected and those that do not, and then estimate the portion of links that connect nodes within the uninfected group.

As previously discussed in this review, Dubé et al. [2011] proposed the use of a new metric called *infection chain* in order to estimate the potential epidemic size accounting for both the direction and the chronological order of the connections. This measure has then been further refined into *ingoing infection chain* and *outgoing infection chain* (Nöremark et al. [2011]). The *ingoing infection chain* was recently applied to create a cumulative scoring scheme for the risk of introducing bovine viral diarrhoea (BVD) in farms in Switzerland (Schärrer et al. [2015]). This scoring was shown to be a valuable tool in identifying farms at higher risk of infection. Restricting testing to farms with scores over a specific threshold value of *ingoing infection chain* resulted in the same number of detected BVD positive farms as testing all farms in the country (Schärrer et al. [2015]). In this study, and similarly to Dutta et al. [2014], a temporal counterpart to the *GSCC*, the *reachability ratio* (*reR*), was also developed to estimate the epidemic size accounting for the chronological occurrence of these contacts, therefore, further refining this estimation (Schärrer et al. [2015]).

This is not a comprehensive review of the studies addressing the temporal dynamism of livestock networks, nevertheless, it provides sufficient evidence of the importance of accounting for the temporal framework when data availability enables this type of analysis. Unfortunately, in settings where data on livestock movements are still poor and not accurate, it is extremely complex to capture the temporal dimension of contact networks.

2.12 Network analysis and the basic reproductive rate

For decades, the modeling framework for the study of the spread of infectious diseases through a population was based on the mass-action principle, defining the number of new infected cases in a time interval as the product of infected and susceptible cases in the previous time interval (Danon et al. [2011]). This approach has then been developed towards a more flexible methodology known as compartmental modeling, which subdivides host populations by disease status for predicting the transmission of infectious agents. In the basic compartmental models the susceptible, infected and recovered proportion of the population are described (SIR models) (Danon et al. [2011]). Within this framework the initial growth rate for the infected class is determined by the *basic reproductive rate* (R_0) of a disease (Dohoo et al. [2012]). There are a number of approaches for estimating the R_0 (Li et al. [2011]) and in most epidemiological models both the R_0 and the *epidemic threshold* are determined by a combination of epidemic and social parameters. Epidemic parameters relate to the transmission efficiency per contact, depending on the intrinsic characteristics of an infectious agent such as transmission and recovery rates, and incubation and infectious periods. Social parameters are, instead, related to the patterns of contacts between individuals in the population (Volz and Meyers [2009]).

Compartmental modeling assumes that potentially infectious contacts are occurring at random, assuming an average contact rate per unit of time (Keeling and Eames [2005]). Consequently, population estimates of R_0 can hide considerable individual variation in infectiousness of network nodes, as highlighted during the global emergence of severe acute respiratory syndrome (SARS) (Lloyd-Smith et al. [2005]). These authors observed, in particular, the central role in the epidemic played by "super-spreading events", in which certain individuals infected unusually large numbers of secondary cases. Ancel Meyers [2007] and others (Cross et al. [2007]; Tildesley and Keeling [2009]; Li et al. [2011]) in fact showed that the R_0 depends explicitly on the structure of the contact network. In particular, the R_0 depends on centrality measures, specifically on the mean degree and mean squared degree (Cross et al. [2007]; Tildesley and Keeling [2009]; Li et al. [2011]). Therefore, in the context of heterogeneous networks, estimating the R_0 for an infectious disease may be misleading if not appropriately accounting for the structure of the contact network (Ancel Meyers [2007]).

2.13 Constraints of network analysis

Network analysis has shown the importance of considering the topological structure of movement networks in epidemiological studies. The structure of the contacts showed to impact both the size and the time scale of epidemics. Nevertheless, the application of network analysis may be limited by potential constraints. The lack of sufficient data may prevent the application of SNA. In countries or regions where information and data collection are limited due to institutional, political, economic and social constraints, network samples have been used to extrapolate information on the structure and the behaviour of the wider system (Dubé et al. [2011]; Dean et al. [2013]; Nicolas et al. [2013]; Vallée et al. [2013]). Alternative techniques, such as participatory epidemiology, have also been applied to collect data to perform network analysis and identify patterns of risk for national and transboundary disease spread in lower income regions (Martínez-López et al. [2009]; Dean et al. [2013]; Nicolas et al. [2013]). However, as for all epidemiological studies, good quality information is a fundamental prerequisite. Collection of data through surveys or questionnaires could introduce potential random and systemic errors in the study. Selection of the most appropriate epidemiological units and connections for defining the network structure are also key information. To minimise the level of bias in the estimation of the network metrics and, therefore, in the inferences based on them, the method used to select the appropriate epidemiological units and connections should aim at identifying the most complete and comprehensive available data.

2.14 Imperfect data in network analysis

It is often very complex, in real world networks, to capture their entire structure. Social network data is often incomplete, missing some nodes or connections in the network. The main sources of incompleteness are the so-called boundary specification problem and the accuracy of information (Kossinets [2006]). While both lead to the non-inclusion of all nodes or connections in the network, the former source of incompleteness is due to the artificial setting of boundaries of a network and the latter to actual missing of information (e.g. non-response in social network surveys).

Effects of incomplete data on network properties have been studied particularly in the social sciences. The most common approach has been to randomly remove nodes or edges from empirical or simulated model networks and subsequently observe and measure the effects on the centrality measures. Costenbader and Valente [2003] studied the performance of centrality measures from empirical data under different research constraints, estimating how well measures extrapolated from sampled sub-networks approximated those calculated from the entire network. Among centrality measures, *eigenvector centrality* and the *in-degree* had the smallest variation when the network data were incomplete. These measures showed high correlations, in the 0.7-0.9 range, between the actual and the sampled network even at low sampling rates with 50% missing data. Smith and Moody [2013], instead, observed a high robustness of *in-degree* and *closeness* to missing nodes or connections. They also reported that the *average path length* tended to be overestimated while the *clustering coefficients* remained largely stable. According to these authors, networks that are more cohesive are also more robust to missing data whereas smaller and less centralised networks tend to be more sensitive showing higher levels of bias in topology measures. In other studies, the examination of randomly generated networks to explore the effect of missing nodes or connections on the accuracy of the estimation of the centrality measures, revealed that *degree*, *closeness*, *betweenness* and *eigenvector* were similarly affected (Borgatti and Everett [2006]; Kossinets [2006]).

Interestingly, despite studying artificially generated networks, Borgatti and Everett [2006] described that missing nodes have generally a lower impact than missing links. However, it is important to note that random networks tend to have little clustering and more consistent degree distributions compared to small-world networks, making their comparison to real world networks less appropriate. Similarly, Wang et al. [2012] studying both empirical and randomly generated networks, found that centrality measures were robust to measurement error. Interestingly, this study also showed that all the tested scenarios of incompleteness affected top ranking nodes far more than middle- or low-ranking nodes, based on their centrality measures. This finding suggested that gathering more complete data for highly active nodes is a more effective strategy than attempting to collect less complete data for all nodes (Wang et al. [2012]).

All these studies indicate that even with relatively high levels of missing data many network measures can be evaluated accurately, providing reliable estimates of network properties. Nevertheless, measurement bias tends to increase with more missing data (Borgatti and Everett [2006]; Kossinets [2006]; Wang et al. [2012]; Smith and Moody [2013]). The exact relationship between bias and missing nodes varies, however, depending on the type of network. For example, larger, more centralised and cohesive networks are generally more robust to missing data. The understanding of the effects of incomplete data remains limited, particularly for empirical studies of animal social networks. Furthermore, studies of incomplete data have typically removed data at random, but conversely, in empirically collected data the sampled nodes and edges are rarely a random subset of the true network's nodes and edges. In fact, in a non-random sampling framework, the probability of a node being sampled is related to its centrality and with its rate of interactions.

In conclusion, these considerations suggest that, under various circumstances and with careful consideration of the potential shortcomings of imperfect data, network analysis is capable of providing a useful approach to characterise network properties and study network interventions.

2.15 Application of network analysis in risk-based surveillance and control

The primary objectives of risk-based veterinary surveillance are “to identify surveillance needs to protect the health of livestock and consumers, to set priorities and to allocate resources effectively and efficiently” through the stratification of the target population into categories that display heterogeneity in hazard probability or in the severity of consequence if the hazard is present (Stärk et al. [2006]). For diseases where live animal trade constitutes a main risk for introduction and dissemination, information about animal movements and the resulting contact network are, therefore, of great value for surveying and controlling purposes. Consequently, including network analysis parameters in the identification and selection of epidemiological units could complement current surveillance systems that are commonly disease centered, and could provide key information to increase the surveillance sensitivity for these diseases compared to random sampling (Hardstaff et al. [2015]).

An example of the practical application of network analysis parameters to increase surveillance sensitivity is provided by Frössling et al. [2012]. Combining a cross-sectional study for endemic viral infections and a risk-based approach centred on network analysis of cattle movements (in particular applying *ingoing infection chain* and on *in-degree*), they were able to demonstrate the detection of significantly more positive cases of bovine coronavirus (BCV) compared to a random sampling in the Swedish cattle population. More recently, a positive association between network centrality indicators of incoming contacts, as *ingoing infection chain* and *in-degree*, and bTB infection status of cattle herds was also found by Palisson et al. [2016] in the network of French cattle movements between administrative districts. Similarly to these results, in the Afar Region of Ethiopia herd's *in-degree* and *betweenness* centrality within a local contact network between herds were positively correlated with the risk of being infected with bTB (Sintayehu et al. [2017]).

Building on previous findings of association between BCV status and incoming network centrality measures, Frössling et al. [2014], developed a more elaborate metric to increase surveillance sensitivity. The *probability of disease ratio* (*PDR*) is an example of a disease-specific measure incorporating network metrics. This metric combines direction and size of the contacts as well as the temporal order they occur, in the form of the *in-degree* and *ingoing infection chain*, accounting, simultaneously, for differences in the prevalence or the probability of disease between units of interest in the contact chain (Frössling et al. [2014]). The application of this metric on prevalence data for Q fever in livestock in the Isle of Gotland in Sweden enabled this study to accurately identify infected and not infected herds, showing that the difference in *PDR* between these herds was significantly higher compared to the difference in *in-degree* or *ingoing infection chain* as such. This finding indicates that combining network centrality measures with more conventional epidemiological measures may represent a valuable improvement in surveillance and control efforts where both these data are available.

A similar conceptual approach in computing a cumulative score for the risk of introducing BVD was undertaken by Schärrer et al. [2015]. They used an aggregated scoring method to rank farms in Switzerland including the maximum monthly *ingoing infection chain*, the average number of animals per incoming movement, the use of mixed alpine pastures and the number of weeks a farm had movements registered over one year. They were able to demonstrate that restricting testing to farms with a score higher than 2, in a range from 0 to

5, would have resulted in the same number of detected BVD positive farms as testing all farms. Their results show that some farms are at higher risk of being infected with BVD due to their position in the trade network and, therefore, that risk-based surveillance including network analysis could provide a tool for a more cost-effective surveillance. Evidence that cattle movements were associated with an increased risk of herds being seropositive for bovine viral diarrhoea virus (BVDV) was also observed by Gates et al. [2014]. Interestingly, they showed that the herds displaying a significantly higher level of *betweenness* in the contact network were associated with an increased risk of being seropositive for BVDV Gates et al. [2014].

These considerations seem to support the hypothesis that a measure combining network parameters alongside with demographic and managerial practices and, ideally, with laboratory results, would probably provide a more powerful and advanced tool for risk-based control and surveillance strategies. Network analysis could, therefore, represent a key component for designing and monitoring more cost-effectively risk-based surveillance and control interventions.

2.16 An overview of Cameroon

2.16.1 Introduction

This project was carried out in the Republic of Cameroon, a country located in a strategic location at the edge between West and Central Africa. Cameroon extends from 2° to 13° N and ranges from the equatorial forest in the southern areas of the country to the Sahelian zone in Lake Tchad with a total land area of 475 412 Km^2 (Pamo [2008]). Cameroon's 2015 human population was estimated at 23.3 million and is projected to reach 33 million by 2030 and around 49 million by 2050 (Linard et al. [2012] - World Population Prospects The 2015 Revision). The country is overall sparsely populated, with an average of 48 people per Km^2 with about 50% of the total population living in rural areas and whose livelihood depends on agriculture and livestock (Linard et al. [2012] - World Population Prospects The 2015 Revision). Life expectancy at birth for the period 2015-2020 is estimated at 57 years, ranking 181st globally.

Yaoundé is Cameroon's capital city with a population of around 1.3 million, which makes it the second-largest city in the country after Douala, which has more than 1.4 million residents. The country is composed of 10 Administrative Regions with marked environmental diversity and climatic contrasts. All the African ecological zones, stretching from equatorial to sub-Sahelian zones, and almost all the intertropical climates are represented in the country (Pamo [2008]). Forest areas cover 41.7% of the country, while agricultural land accounts for 20.5% of the territory (FAO - NationsGeoNetwork Team [2005]).

National gross domestic product (GDP) per year is around USD 29 billions (current US Dollars in 2015) (worldbank.org [2015]) with agriculture contributing 20.6%. It is the third major resource for the Cameroonian economy after the tertiary service sector (52.1%) and industry (27.3%) (cia.gov [2015]). Importantly in Cameroon, the livestock sector represents a source of revenue to more than 30% of the rural population, and contributes to almost 20% of the overall agricultural gross domestic product (GDP) (Pamo [2008]).

The livestock sector is predominantly based on production of cattle, small ruminants, pigs and poultry. Apiculture and aquaculture have only recently been introduced and still remain a minor contributor to the livestock sector in economic terms. The main livestock production areas in the country are located in the Soudano-Sahelian zones in the Adamawa, North, Extreme North, North-West and West Regions (Pamo [2008]). Ruminants are the most widespread livestock in Cameroon and the production system is almost exclusively extensive relying on natural grazing. The cattle population of Cameroon is currently officially estimated to be 6.5 million animals with around 400,000 heads destined for meat consumption annually, leading to a total of almost 90,000 tons of meat yield nationally (MINEPIA [2014]).

There are three types of livestock production systems in Cameroon including pastoralist, in less populated areas, beef and dairy small holder farmers and cut and-carry feeding, in more densely populated areas. The pastoral management system in natural free grazing areas is by far the most common practice in cattle rearing. In the context of such an extensive grazing system, cattle normally find their fodder in the natural grasslands and savannahs and by scavenging of crop residues. Sedentary production system, instead, is mostly limited to small herds and in areas where crop-based agriculture is the main activity and livestock raising is complementary. These sedentary herds are mostly of goats and sheep, and less frequently of cattle.

2.16.2 Cattle population in Cameroon

Cattle are found throughout Cameroon but the major production areas are the Adamawa, North, Extreme North, West and the North-West Regions, where over 90% of the estimated national cattle population is to be found (Kameni et al. [1999]) (Figure 2.2). The East Region, though not a major production zone, is a major transit zone for transhumant livestock from northern areas of the country and for cattle directed to and arriving from the Central African Republic (Kameni et al. [1999]).

The traditional pastoral system, despite very low inputs and a low productivity, has, over the years, represented the source of beef production of the country. Historically, Cameroonian cattle production has been undertaken by the Fulani ethnic group, a pastoral community spanning Central and West Africa (Burnham, Philip [1996]). Cattle rearing is key to the Fulani culture. It is a direct source of food, mainly through meat and milk production, but importantly it is also the core financial capital for the household, as well as having a significant social value. In Cameroon only a minor component of cattle production is undertaken by non-Fulani breeders (Bronsvoort et al. [2003]).

Local Cameroonian cattle breeds are of two types: *Bos indicus* and *Bos taurus*. Local humpless *Bos taurus* form only about 1% of Cameroon's cattle population, and are mainly represented by the Namshi, N'Dama, Kapsi and Bakoussi breeds (Pamo [2008]). A small percentage of *Bos taurus* cattle are imported breeds for cross-breeding purposes in semi-intensive rearing, mostly by non-Fulani dairy farmers. The most recent exotic taurine breeds introduced in the country are Holstein-Friesian and Jersey type animals (Bayemi et al. [2005]). The vast majority of cattle in the country are *Bos indicus* and their herds are reared on extensive communal pastures. The main breeds are the Adamawa Zebu or Gudali breed and the Mbororo, or "zebu of the north", which can be further distinguished into white and red Mbororo (Pamo [2008]). While the Mbororo can be found across the whole country, the Gudali is found almost exclusively in the Vina Division of the Adamawa Region. Cross-breeds are widely spread across the country.

2.16.3 Cattle movements

In Cameroon, as across a number of other countries in SSA, livestock mobility is a central strategy of adaptation to the ecosystem as well as representing an

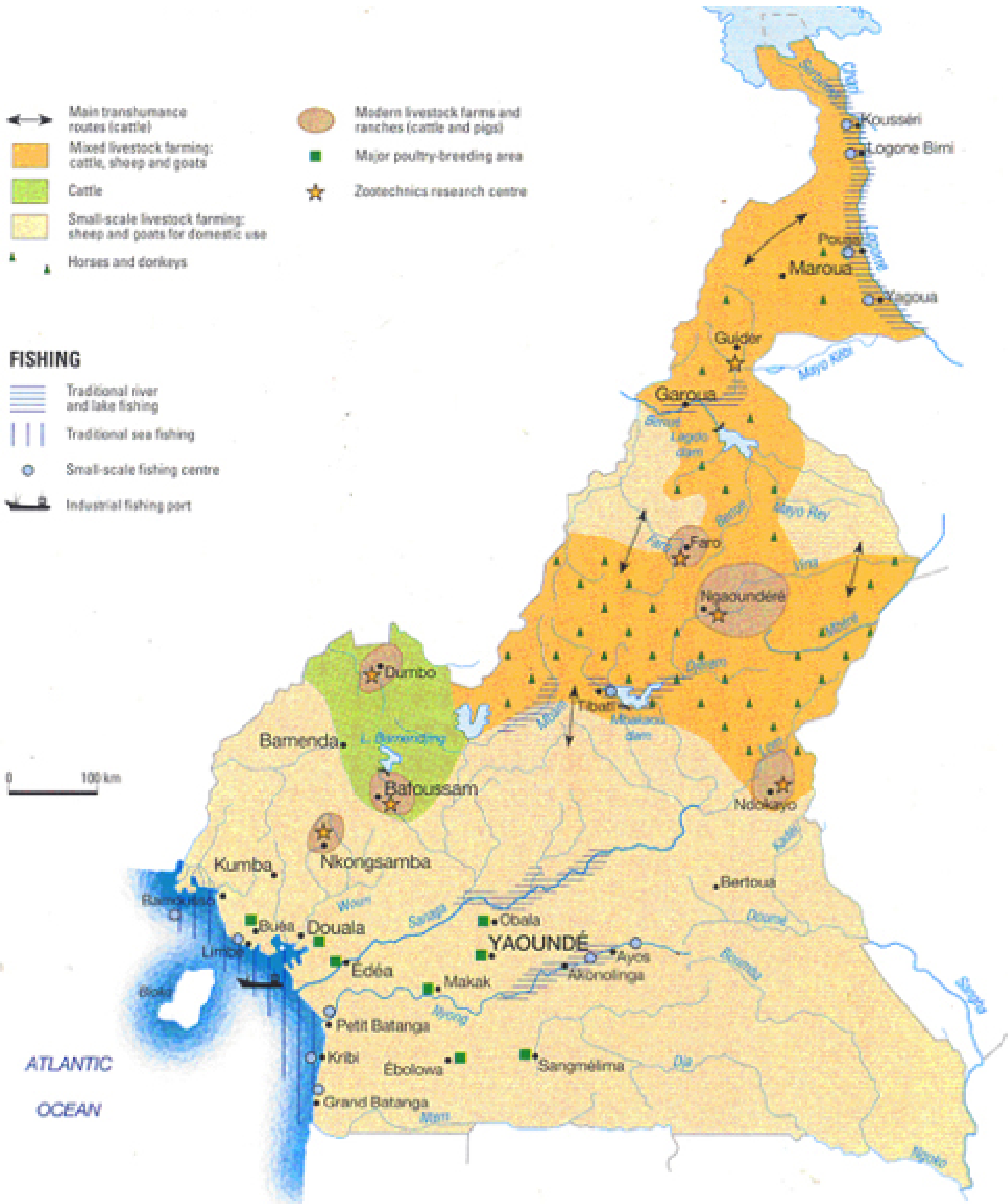

Figure 2.2: **Cameroon livestock production map.**
Distribution of the livestock production systems and zones across the country. The area in dark orange indicates the mixed distribution of large and small ruminants. The area in green, corresponding to the North-West Region, shows that only large ruminants are essentially present in this specific area. (Source: Pamo [2008]).

important component for key economic activities in the livestock value chain. Trade and transhumance are the main determinants of cattle movements.

Cattle transhumance

In Cameroon, although bulls are usually constantly kept within the herd, the majority of calving are occurring during the rainy season when environmental conditions are favourable (Njoya et al. [1999]). In contrast, during the dry season transhumance movements represents a common practice for many herds across the country in order to cope with ecological and environmental constraints. During this period a number of cattle herds from the main livestock production areas of the country are moved in search of greener and fresher pastures and of available water. Transhumance routes follow diverse paths within and across Regions. In the Extreme-North, North-West and West Regions most cattle herds tend to undertake an "internal migration" within the Region (Xiao et al. [2015]). Differently, herds normally located in the North and Adamawa Regions seem to be more mobile, migrating both "internally" and towards the southern Regions of the country or towards the neighbouring country of Central African Republic (personal communication MINEPIA). Main transhumance destinations within Cameroon are represented by savannah areas of the Adamawa, Central and East Regions (Figure 2.3). However, little knowledge of the trajectories and of the actual grazing locations and transhumance destination is currently available.

Cattle trade movements

Cattle are traded within Cameroon as well as through the country to neighbouring countries. Trading routes almost divide the livestock production regions of the country in two distinct entities: the North and Extreme-North Regions mainly orientated on local trade and towards the Nigerian market, while the Adamawa, the North-West and the West Regions are orientated towards the southern areas of the country (personal communication MINEPIA).

Informal communications collected during the fieldwork of this project suggested that the main destination of animals that enter from Chad into the Extreme-North Region of Cameroon is the Borno State of Nigeria. However, the relatively recent instability in the region and the rise of insecurity due to the conflict between the regional governments and the terroristic group Boko Haram has led to changes in these established patterns. Notably the number of imported animals from Chad dropped reducing the number of cattle traded towards Nigeria. As a consequence, economic losses have affected the local stakeholders (mainly herders and traders), and part of the local surplus of animals has started being directed towards the southern Regions of Cameroon increasing their movements from the northern toward the southern parts of the country (personal communication, MINEPIA).

Cattle entering Cameroon from Chad and the Central African Republic through the North and Adamawa Regions, instead, tend towards two main destinations. On one side towards the Adamawa State of Nigeria and on the other side towards southern Cameroon. This latter destination is then further fractioned towards the main urban agglomerations of the country, notably Douala, Yaoundé, Ebolowa and Limbe as well as towards the neighbouring countries of Gabon, Equatorial Guinea and the Republic of Congo. This international transit of livestock is officially regulated through official controls at the entry and exit points and during transit within Cameroon. Nevertheless, traded animals mix with national herds both at usual grazing locations, livestock markets or at transhumance zones. In the transhumant zones they are also likely to come in contact with wildlife through sharing of common pasture and drinking spots, as well as by direct contact (Bronsvoort et al. [2003]).

The combination of trade-related and pastoral movements creates a complex and heterogeneous system of movements at local and national levels which is still poorly understood but that is increasingly needed to better design animal health management strategies for the development of the livestock sector in Cameroon.

2.16.4 Cattle and other livestock infectious diseases in the country

Major constraints to the development and improvement of livestock production in the country are represented by the endemic and transboundary infectious diseases. Trade, marketing and transhumance as well as poor management practices of livestock are major pathogen distribution mechanisms. Together with pests and parasites, contagious epidemic pathogens hinder the development of the livestock sector by both lowering production efficiency and competitiveness, and precluding the access and competitiveness to the international market.

The close economic dependence on livestock of the Cameroonian rural population, and the higher risk of exposure to zoonotic diseases due to closer animal contact, clearly depicts the vulnerability of a significant part of the human population towards infectious diseases. Livestock diseases directly affect animal health and indirectly impact the livelihood of rural households. The risk of infection and of developing disease is intuitively not only confined to the population directly involved in activities with livestock such as animal husbandry or processing of animal products, but multiple pathogens are also transmissible through

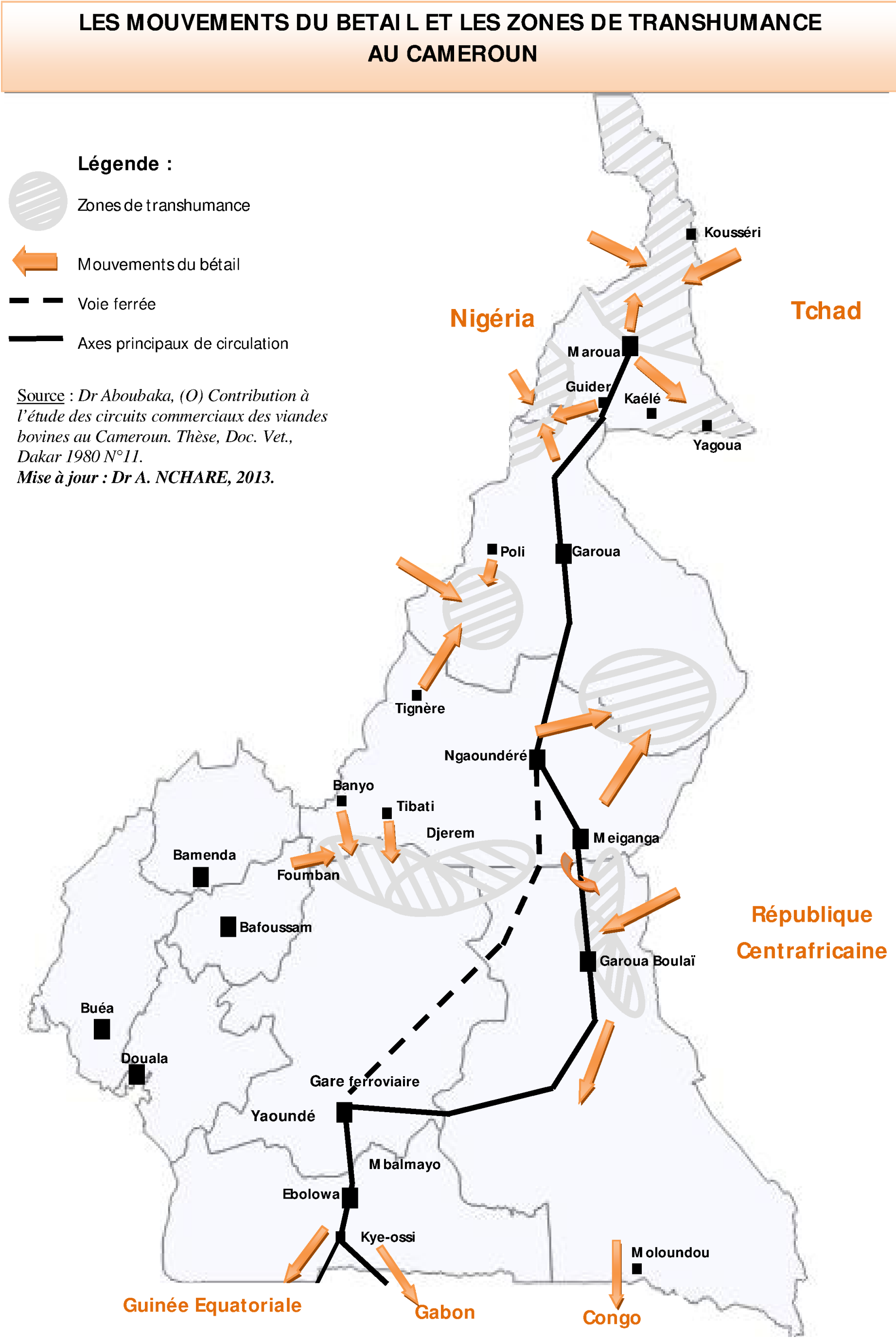

Figure 2.3: **Transhumance cattle movements in Cameroon.** The grey areas represent the known transhumance zones in central and northern Cameroon. The orange arrows indicate the direction of the known movements of transhumant herds during the dry season. (Source: Dr Aboubaka "Contribution à l'étude des circuits commerciaux des viandes bovines au Cameroun", 1980. Mise à jour Dr Nchare, 2013.)

the consumption of livestock products, therefore, being able to percolate down the livestock value chain.

Major zoonotic pathogens in the cattle population in Cameroon include bovine and zoonotic tuberculosis (Egbe et al. [2016]; Kelly et al. [2016]), brucellosis, leptospirosis, Q fever and Rift Valley fever (RVF) (Scolamacchia et al. [2010]). Tuberculosis is a key bacterial zoonotic disease in the country. In cattle it is mainly caused by *Mycocterium bovis*, responsible for bovine tuberculosis (bTB). In Cameroon bTB is widely spread across the country and a recent article studying mycobacterial lesions at abattoirs located in the main livestock production areas of the country reported a higher prevalence in the North and Extreme North Regions of the country compared to central Cameroon (Egbe et al. [2016]).

Bovine dermatophilosis, or streptothricosis, caused by *Dermatophilus congolensis*, a major bacterial disease affecting cattle in Cameroon and with zoonotic potential, is a common pathogen in the warm humid tropics (Zaria [1993]). Dermatophilosis is widely recognised as an important endemic condition by farmers across the SSA showing, in some areas, a herd prevalence of >90% (Awa and Achukwi [2010]). In Cameroon it is a leading cause of production loss and has been identified as the third most important cause of milk loss in zebu/exotic cross-breed dairy cattle (Awa and Achukwi [2010]).

Non zoonotic diseases, instead, have indirect economic and social impacts on the human population through their direct effects on animal health and productivity. Reduced fertility, drop in milk production, loss in weight gain and immunosuppression are only some of these effects. Direct loss of animals due to infectious diseases outbreaks is also not uncommon in every region of the country. The diseases affecting cattle herds in Cameroon that have been identified as major constraints for the development of the livestock sector are FMD, pasteurellosis, CBPP, tick-borne diseases and trypanosomiasis (Awa and Achukwi [2010]).

Bovine endemic bacterial diseases of cattle, such as pasteurellosis, black quarter, and CBPP are controlled through annual vaccination campaigns and, therefore, epidemic outbreaks are not frequently reported. Nevertheless, pasteurellosis and CBPP are still major causes of morbidity and mortality among cattle herds in the country (personal communication, MINEPIA). CBPP, in particular, is a highly contagious disease of ruminants with potential for rapid spread caused by *Mycoplasma mycoides* subsp. *Mycoides.* It is regarded as one of the major TADs in the Region and a recent study found a prevalence of 30% among cattle slaughtered in the regional abattoir of the North Region of Cameroon (Wesley et al. [2015]).

Similar to the situation across SSA, FMD is endemic in Cameroon. The organism which causes FMD is an *aphthovirus* of the family *Picornaviridae* and serotypes O, A and SAT2 of FMDV are known to have been circulating in Central Cameroon since at least the 1990s (Bronsvoort et al. [2004a]) while also SAT1 and SAT3 have been recently identified in the Far North Region of Cameroon (Pomeroy et al. [2015]). Although in the Adamawa Region of Cameroon 60% of the cattle herds were estimated to be infected, knowledge of herd prevalences in other Regions of the country is still very limited (Bronsvoort et al. [2004a]).

Animal trypanosomiasis is also affecting the cattle population in Cameroon causing losses in production as across the whole SSA (Mattioli et al. [2004]). Bovine trypanosomiasis caused by both *Trypanosoma vivax* and *Trypanosoma congolense* is more prevalent in areas where rainfall is above 1000 mm where also vector density is higher (Awa and Achukwi [2010]). Understandably, these areas are often destinations or transit zones for transhumant herds. Despite a reduction in vector population during the dry season and the acknowledged importance of treating animals with trypanocides on return from transhumance by herdsmen in Cameroon, trypanosomiasis remains an important constraint for livestock development in Cameroon (Awa and Ndamkou [2006]).

An important viral disease that can provoke mortality rates as high as 40 percent and chronic debility in infected cattle is lumpy skin disease (LSD) caused by a virus of the family *Poxviridae* (Glyn, Davies [2010]; OIE [2012]). However, despite the economic and production impact of LSD, to our knowledge very little is currently known about the biology and epidemiology of the disease in the country.

Another viral disease present in the country is the BVD, caused by a virus of the family *Flaviviridae*. Despite the very little knowledge of its occurrence in SSA, in the Adamawa Region of Cameroon herds showed high prevalences of infection, particularly in the higher cattle density areas (Handel et al. [2011]).

2.17 Understanding cattle movements in Cameroon

Various studies have been carried out in Cameroon in the recent past to evaluate the burden of livestock and zoonotic diseases (Bronsvoort et al. [2003]; Bronsvoort et al. [2004a]; Awa and Ndamkou [2006]; Awa and Achukwi [2010]; Scolamacchia et al. [2010]; Handel et al. [2011]; Egbe et al. [2016]) and to identify constraints for disease control in pastoral and small-scale livestock husbandry and production systems (Kelly et al. [2016]). Together, these studies provide a key collection of information for helping developing a situation analysis of animal health in the country. Nevertheless, understanding the patterns of movements of live animals within and across the country is essential for putting the previous findings in the Cameroonian context and for supporting more informed and cost-effective animal health management programmes.

The study of livestock markets and of the cattle trading network in Cameroon represents the main focus of this project, in the attempt to fill the current information gaps for better understanding the implications for the epidemiology of infectious diseases in the country.

In the following chapters methodological approaches applied to characterise the cattle trade system and the herd management practices through this system are presented. Subsequently, methods and approaches to study the trade network and to identify key livestock markets for designing targeted and strategic communication, surveillance and control strategies are described. The factors contributing to cattle price formation at the market level are also investigated in the attempt to provide valuable information for helping future estimations of the burden of these infectious diseases as well as of the impacts of control measures. In addition the seasonal cattle transhumance across the country is investigated through a pilot project aiming at testing the feasibility of empirically studying this seasonal migration and explore the relation with the trading system and the potential implications for infectious diseases epidemiology.

Chapter 3

Project Methodology

3.1 Study area

The major livestock production areas in Cameroon are in the West and North-West Regions and from the Adamawa Region northward (Pamo [2008]). The current project was mainly carried out in these areas of the country. Unfortunately, for security reasons it was not possible to physically visit and sample the North and Extreme North Regions where an established pathway of cattle trade is known to flow from high livestock production regions in Central Africa towards countries with a high demand of animal and animal products in West Africa. Nevertheless, in addition to the West, North-West and the Adamawa Regions, where the bulk of the data collection was carried out, the major livestock markets in the Littoral, Central and South Regions of the country were also visited for this study (Figure 3.1).

The Adamawa Region is mainly a pastoral highland of approximately 64,000km^2, sparsely populated, and a major livestock production area of Cameroon with an estimated cattle population of about 1,250,000 (MINEPIA [2014]). It is situated mainly around 1100 m above sea level. The climate is tropical, usually described as sudano-guinean, with a characteristic unimodal rainfall pattern. There are two major seasons, the wet season which runs from May to September and the dry season from October to April (Pamo [2008]). This Francophone Region is divided into five administrative Divisions (Vina, Mbere, Mayo Banyo, Djerem and Faro et Deo) where around 1.2 million people are living (Linard et al. [2012]). The regional capital is Ngaoundere with a population of about 240,000 people (Linard et al. [2012]).

The North-West Region is an Anglophone region situated in fertile mountainous highlands covering 17,910 km^2. The Region is densely populated with about 1.8 million people, and around the 70% of the population is estimated to live in rural areas (Pamo [2008]). It is located in the mid and high altitude zone of the country between 300 to 3000 m above sea level. The climate is marked by a dry season approximately spanning from November to May and a rainy season from April to October. It is considered the third largest cattle producing area of the country, after the Adamawa and the northern Regions, with an estimated cattle population of 600,000 (Pamo [2008]).

The West Region is another important cattle producing Region, with an estimated population of about 150,000 head of cattle (MINEPIA [2014]). It is located in the mid and high altitude zone of the central-western portion of the country between the Adamawa Region to the north, the North-West Region to the west, the Central Region to the south-east and the Littoral and South-West Regions to the south-west. It is the smallest Region of Cameroon (14,000 km^2) with about 1.8 million people, having the highest human population density in the country (134 inhabitants per km^2) (Pamo [2008]).

Douala, the capital of Cameroon's Littoral Region, is the largest city and the commercial and economic capital of the country hosting the Central Africa's largest port. Yaoundé is the administrative capital of Cameroon and the second largest city in the country and its economy is almost entirely centred around the administrative structure of the civil service and the diplomatic services. Kye-ossi, instead is a relatively small municipality in the South Region of the country and has the peculiarity of bordering with two neighbouring countries simultaneously. It faces Equatorial Guinea to the south and Gabon to the east, and it is an important trading point between these three countries.

3.1.1 Structure of the Ministry of Livestock, Fisheries and Animal Industries

The Ministry of Livestock, Fisheries and Animal Industries (MINEPIA) is responsible for elaborating and implementing policies related to livestock production and health as well as for regulating the animal products industry. The National Headquarters of the MINEPIA are in Yaoundé, while Regional Delegations are present in the capitals of each of the 10 Regions of the country. The Regions of Cameroon are divided into 58 Divisions, or Departments, which are further partitioned into sub-divisions and districts. Divisional Delegations of the MINEPIA are present in each single Division of every Region and sub-Divisional Delegations are present instead at the sub-Divisional level.

The Veterinary Services are present at each level of this structure and they are responsible for the administrative area of competence. Among other activities, these centres are responsible for the implementation of the vaccination campaigns, for surveillance and monitor of infectious diseases and for providing veterinary assistance, as well as monitoring and supervising the activities of the abattoirs when these are present. Another major responsibility of the personnel of the

MINEPIA at district level includes the sanitary control of the livestock markets and the management of these infrastructures in coordination with the municipal authorities where each market is located.

3.2 Investigations of the cattle trade system

3.2.1 Pilot project

At the beginning of May 2014 a preliminary study was carried out to assess the feasibility of the project plan and identify the main challenges and constraints in order to achieve the objectives for this study. After gaining the required authorisations from the competent authorities four livestock markets were visited, Likok and Ngaoundere in the Adamawa Region and Bamenda and Takija in the North-West Region. The documentation available at the market level was examined. Semi-structured interviews were conducted with all the stakeholders at the trading points. This preliminary study enabled to assess the quality and reliability of the available documentation as well as evaluating the weaknesses and strengths of the questionnaires designed for the interviews. Furthermore, the project aim and objectives were presented and discussed with the Regional Delegations of the MINEPIA in the Adamawa and North-West Regions. These meetings, during this preliminary mission of three weeks helped gaining the institutional support essential for the implementation of the project across multiple Regions of Cameroon.

3.2.2 Market identification strategy

The main field work for this project was carried out from September 2014 to May 2015. Upon arrival within each of the Adamawa, West and North-West Regions meetings with the authorities of the Regional Delegations of the MINEPIA were organised. During these occasions general information about the characteristics of the livestock trading system in each Region were discussed and a list of the cattle markets present on the competent territory was obtained and were evaluated in consultation with regional livestock experts. Subsequently, information relative to the commercial connections during the previous 12 months was gathered from all markets included in the MINEPIA registers. However, preliminary data collection from these markets and interviews with local veterinary officials indicated that the list was incomplete. All markets that were not listed in the MINEPIA registers but were identified through their commercial connections and were located within the three study Regions (Adamawa, West and North-West), were added to our data collection framework and subsequently visited.

Within the three administrative Regions of core interest (Adamawa, West and North-West Regions) a total of 52 markets were listed in the MINEPIA register. The preliminary analysis of the information relative to the commercial connections of the listed markets during the previous 12 months identified an additional 7 markets within the three Regions (total of 59 markets) (Figure 3.2). In addition to these 59 markets within the Adamawa, North-West and West Regions, 3 other major national markets, located in high consumption urban areas in the southern part of the country, were included in the study. These were the cattle markets in Yaoundé and Douala and in Kye-ossi, the border town in the South Region neighbouring with Gabon and Equatorial Guinea.

A total of 62 cattle markets within six Regions were visited and active data

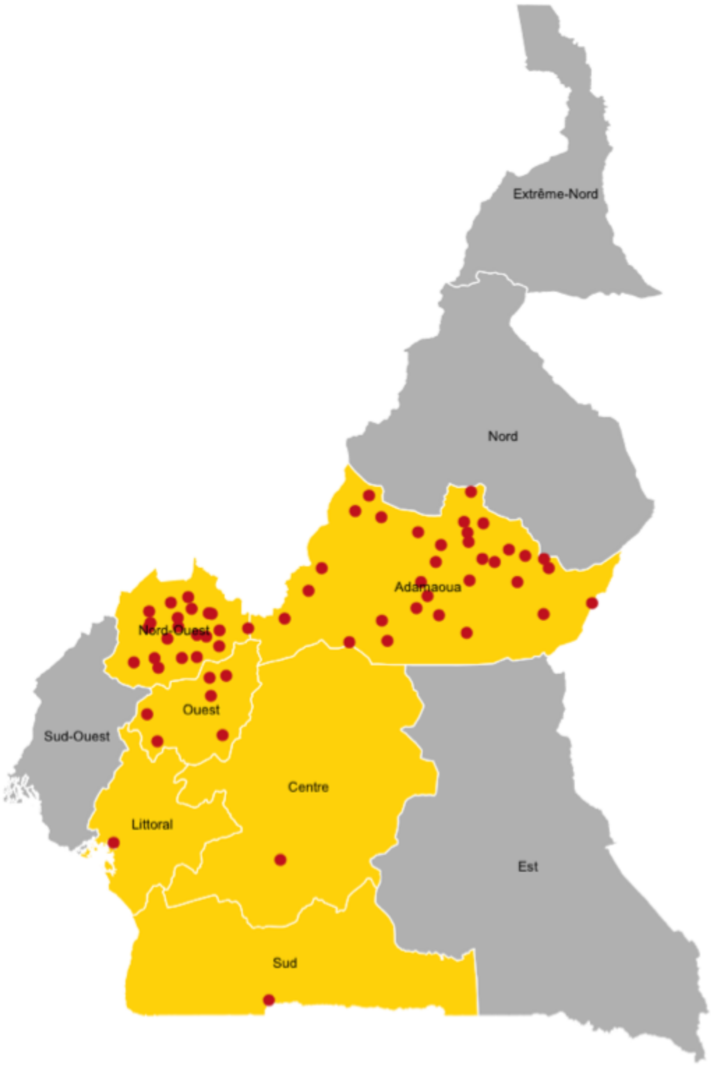

Figure 3.1: **Study area and market locations.**
In yellow are highlighted the Regions where the data collection at livestock markets was carried out. The red dots represent the locations of the livestock markets where the data were collected between September 2014 and May 2015.

Figure 3.2: **Proportions of markets identified through the official list and though the investigation within the three main study Regions.** Blue colour refers to the proportion of the markets that were officially listed while the yellow colour refers to the markets that were not on this lists.

collection was carried out at these locations (Table 3.1). The precise locations of the markets are shown in Figure 3.1. A total of 31 markets were sampled in the Adamawa Region, 22 in the North-West Region and 6 in the West (Table 3.1 and Figure 3.1). The cattle markets were mostly held once a week even tough larger markets, in Yaoundé and Douala, were held up to 6 days a week. The field work was almost entirely carried out by a team of two researchers including an experienced veterinary technician, Saydou Hamman from the IRAD Wakwa (Adamawa Regional Centre of Wakwa) with extensive experience of field research activities in Cameroon and fluent in the most commonly used local languages, particularly of Fufulde (the major language of the Fulani) and Pidgin English.

Table 3.1: Names and Regions of the identified cattle markets across Central and Southern Cameroon.

Region	**Markets location**
Adamawa	Ngaoundere, Ngaoundal, Tello, Banyo, Ngaoui, Galdi, Nyambaka, Likok, Mbang Foulbe, Samba, Mayo Darle, Mbanti Katarko, Martap, Dibi, Margol, Mayo Baleo, Belel, Beka Gotto, Sambo Labo, Alme, Libong, Dir, Meiganga, Garga, Kognoli, Mbe, Dang, Dangfili, Djalingo, Tourningal, Lougga
West	Foumban, Tayandi, Bafang, Bangambi, Maloua, Ngon-Kham
North-West	Bamenda, Takija, Misaje, Binshua, Sabongari, Esu, Wum, Bafut, Kimbi, Subum, Binka, Dumbu, Ntumbaw, Tingume-Babungo, Saje-Babungo, Mbiame, Weh, Wainamah, Acha Tugi, Konene, Lassin, Fundong
Central	Yaoundé
Littoral	Douala
South	Kye-ossi

3.3 Data collection

After obtaining the relevant authorisations for implementing the study, multiple data collection strategies were carried out between September 2014 and May 2015. The different data capture methods are summarised in Figure 3.3. In order to study the livestock trade system and both the trade-related and pastoral transhumant movements, the data collection included diverse questionnaire-based surveys, the collection of official documentation at markets and delegations of the MINEPIA and the implementation of a GPS-tracking investigation. The specifics of the data processing and of the various methodologies used for the analysis of this data are described more in details in the following Sections and in each of the relevant following Chapters of this Thesis.

3.3.1 Official reports and transaction records (*R_1 and R_2 in Figure 3.3*)

The main objective of the data capture strategies carried out at the identified livestock markets, and the relevant delegations of the MINEPIA, was to obtain the most recent information relative to the cattle movements through the trading system. The study of the cattle movement through the trading system focused on a twelve month period, retrospectively starting in September 2013 and ending in August 2014, in order to enable the evaluation of the most recent annual trends in cattle trade.

At the relevant Delegations of the MINEPIA for each identified livestock market official reports on the trading activities (R_1) were examined and scanned or photographed (using a portable scanning device or a smart phone). During the visits at the market these were geolocated (Garmin eTrex Venture) and the official transaction records (R_2) were also examined and scanned or photographed.

Transaction records from the markets and official reports from the offices of the MINEPIA reported similar information across the country. However, some inconsistency was observed in the type of data reported, but above all in the way data was registered in the different Regions. In general, the number of traded animals and the value of the transactions were reported while the origins, destination, animal class and age were not consistently collected across Regions. Some variation was also present in how these data were recorded. For instance, in the Adamawa and part of the West Regions information was always reported for each single traded animal, while in most of the markets located in the rest of the study area (North-West Region and Yaoundé) the information was aggregated by batches of traded animals, therefore making it more complicated to disaggregate this data. Additionally, the official documentation (R_1 and R_2) from the markets located in Douala and Kye-ossi, while reporting number, origins and destinations and animal type of the batches of traded cattle, did not consistently include the value of the transaction for each recorded batch. When this information was missing in these two markets it could only be obtained through a questionnaire-based survey described in the subsequent section of this chapter (Q_1).

3.3.2 Interviews with the veterinary services (*Q_1 in Figure 3.3*)

A complementary research strategy aimed both at confirming the data obtained from the official reports and the transaction records (R_1 and R_2) and at collecting additional relevant information (e.g. management practices of the cattle and other livestock at the market place). During the visits at the relevant office of the MINEPIA competent for each market, semi-structured interviews were carried out with the veterinary officer (Table 3.2). The questionnaire-based interview (Q_1) aimed at investigating the origin and destinations and commercial values of the traded cattle confirming the information gathered through the official documentation (R_1 and R_2) and complementing it when missing (inconsistent reports of the value of transactions for the markets in Douala and Kye-ossi), as well as at gaining other relevant knowledge. Questions investigated which other animals were traded at the site, main diseases observed at the market, transhumance destinations in the area and estimation of the numbers of stakeholders (such as traders, farmers or butchers) operating in the market for each trading day. The questionnaires were administrated both in French and English, depending on the official language of the Region of Cameroon, and took around 20-25 minutes to administer. The semi-structured nature of the questionnaires also provided the opportunity to discuss additional relevant information depending on the circumstances and on the availability of the interviewee. The questionnaire is available in Appendix A (Figure A.1).

3.3.3 Interviews with other market stakeholder's (*Q_2 in Figure 3.3*)

Structured questionnaire-based interviews (Q_2) were carried out with the various stakeholders attending the marketing day (Table 3.2). Cattle traders, herders and butchers were interviewed with two main objectives. To obtain (1) a second confirmation of origins and destinations of traded animals at that market, and (2) information on trade practices and on the characteristics of the traded animals. This included interviewee background, number of traded cattle, average time before introduction in the herd of newly acquired animals, transhumance habits and destinations and details about the negotiations on that specific mar-

Table 3.2: Number of cattle markets per Regions and of questionnaires carried out in each Region on Cameroon.

Region	Markets	Questionnaires vet. services (Q_1)	Questionnaires other stakeholders (Q_2)
Adamawa	31	31	332
North-West	22	22	196
West	6	6	42
South	1	1	0
Central	1	1	10
Littoral	1	1	11
Total	62	62	591

keting day such as the number of traded and unsold cattle. Due to the chaotic nature of the sampling context, where negotiations and transactions need to be carried out in a relatively short time period, the questionnaire (Q_2) needed to be concise and rapid to administer. As a consequence, a convenient sampling strategy was the only applicable for the data collection in this type of environment. Each questionnaire-based interview took only between 5-10 minutes and were administrated either in French, English, Fufulde or Pidgin English depending on the language of the interviewee. A copy of the questionnaire (Q_2) is given in Appendix A (Figure A.2).

3.4 Data entry and processing

Data entry and management approaches are summarised in Figure 3.3, together with the already described data collection strategies.

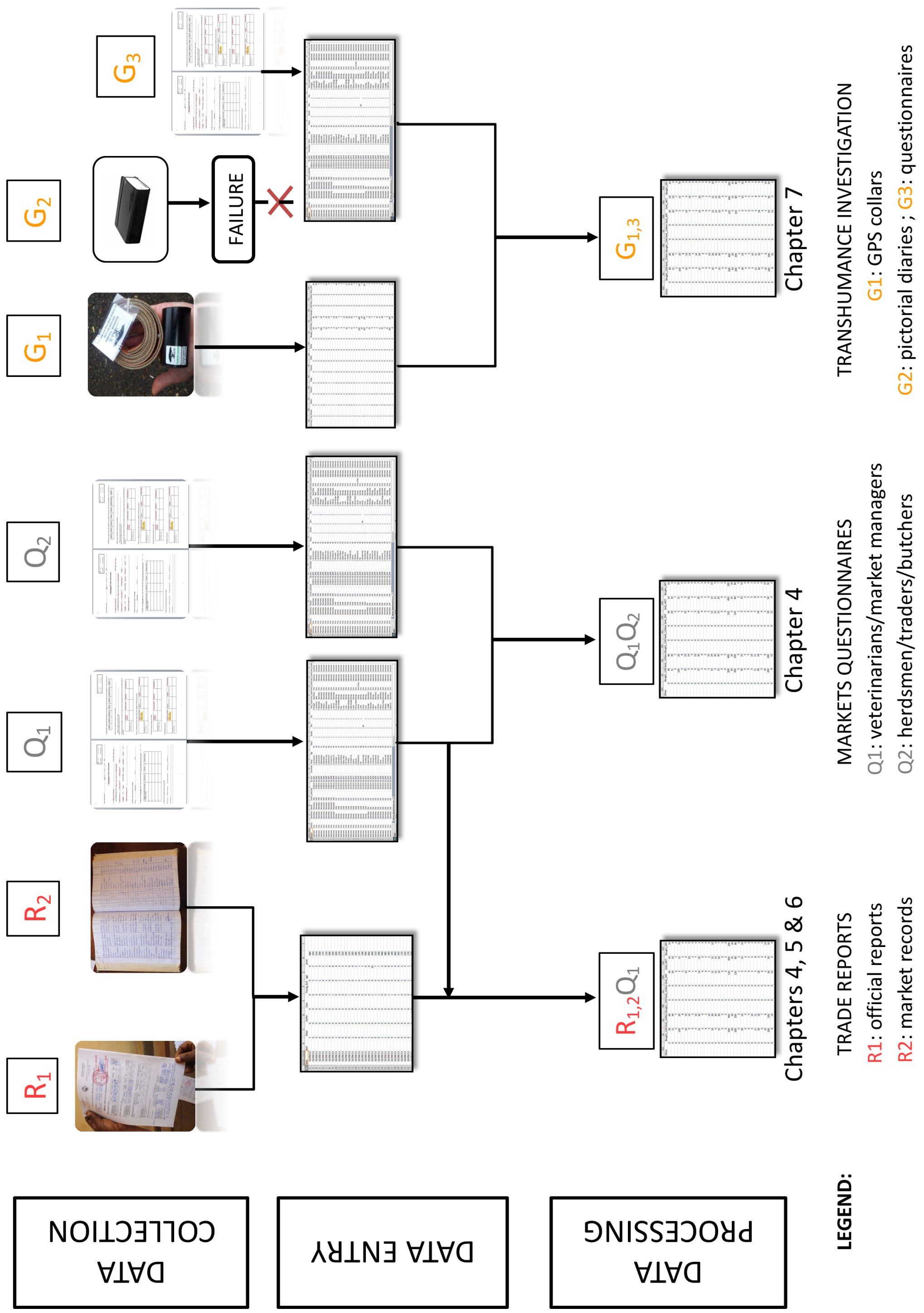

Figure 3.3: **Flowchart of the data collection, entry and processing.**

Once the transaction records and the official reports were scanned they were archived as pdf files. These files were then manually transcribed to pre-designed Microsoft Excel spreadsheet and stored as separate .csv files for each of the 62 sampled markets. To minimise the errors introduced in this process data were double entered by 2 independent personnel and then cross-checked for discrepancies. If these were identified, original scans were re-examined and data re-entered in the master database. The date and the price of the transaction as well as the sex, age and type of the traded cattle and the origin and destinations were stored in the spreadsheet. However, as mentioned in section 3.3.1 this was not consistently recorded across the study area. In particular, in the North-West Region, part of the West Region and in the market of Yaoundé data was aggregated by batches of traded animals and it was not possible to reliably extrapolate the traded value of an individual animal. Further, for some records at the markets of Douala and Kye-ossi the value of the traded cattle could only be estimated through structured interviews (see Section 3.3.1). Additionally, in some of the markets in the study areas origins and destinations were not consistently recorded on the transaction records (see Section 5.2.2 for specific details). When not available from the records, this information was obtained from the official reports collected from the offices of the MINEPIA and from the questionnaires conducted with the official veterinarians responsible for each cattle market (see Section 5.2.2 for specific details). Data processing and manipulation was carried out using scripts within the R environment (R Core Team [2013]).

The hard copies of the questionnaires that were carried out with both the veterinary officials and the other stakeholders attending the cattle markets were transcribed into two different pre-designed Microsoft Excel spreadsheets and stored as separate .csv files. Questionnaires were treated anonymously therefore they were assigned an identification number relative to the market and the date of collection.

3.5 Transhumance data collection

3.5.1 Study area and herds selection

At the beginning of the field work in September and October 2014 consultations with veterinary officials and with other markets stakeholder's at various market locations enabled us to identify owners of cattle herds willing to participate in a pilot project to test the feasibility of tracking cattle herds during the seasonal transhumance. This study was carried out in the Adamawa Region, which is know to be both an origin and a destination of cattle transhumance. The dry season in the Adamawa Region normally spans October to April of the following year (Pamo [2008]), with some annual variability depending on the arrival of the rains. Between October and November 2014 ten cattle herds were identified that were prepared to participate in the study. They were selected with the objective of including different Divisions within the Adamawa Region as origins of transhumant herds. More details on the GPS tracking approach and animals selection are provided in Chapter 7 of this thesis.

3.5.2 GPS Device (*G_1 in Figure 3.3*)

Collars were sourced from Savannah Tracking Ltd, (Nairobi, Kenya). We chose light GPS collars (weight: 320 g) in order to minimize the discomfort for the animals. These devices were able to transmit data through the mobile phone (GSM) network. Additionally, they allowed storage of GPS data in an on board memory card as a backup option. The battery of these devices was used to power the GPS unit itself along with related electronic components which store data. A total of 10 collar devices were sourced for a total cost of 5,240 USD, including the expenses to a national mobile operating company for accessing the GSM network across all the country for a twelve-month period. Under ideal conditions, the battery was set to last for 360 days storing 12 GPS locations per day while the memory capacity could enable to store up to 20,000 positions.

A custom made software from Savannah Tracking Ltd was used to remotely manage the devices and to follow their trajectories. The collar obtained positions via GPS at user defined intervals. Programming of the data collection schedule and data recording parameters was done by accessing the online software setting key parameters to the unit (collar must be within mobile phone coverage). Stored positions were transferred through the GSM network via short message service (SMS), stored into servers and then downloaded through the Internet. In the case of GSM coverage failure, the backup memory offered the opportunity for storing the data.

3.5.3 Additional strategies for transhumance data collection (*G_2 and G_3 in Figure 3.3*)

Herds are usually taken on transhumance and supervised by one or more herdsmen or keepers. We wanted to obtain information on the herds management practices during this long distance migration through the use of pictorial diaries (G_2) provided to the keepers escorting the animals. Given the variable literacy we deliberatively avoided using written information on the diaries and only relied on images to get information on the daily activities of the herd. Stops at natural or artificial water points, encounter with other cattle herds, other livestock or diverse types of wildlife were included in the images as well basic characteristics of the grazing areas. Participants were asked to tick boxes beside these different pictorial references on daily basis. An image of the daily page used in the diary for this pilot is provided in Appendix C (Figure C.1).

Upon return from the transhumant migration in May 2015 herdsmen or keepers were then interviewed to obtain information on the past transhuamnce. The semi-structured questionnaires (G_3) investigated the daily routines of the herd, the interactions with livestock or wildlife populations, infections suffered, and information on births, deaths as well as sales and acquisitions of animals. A copy of the questionnaire used for this pilot project (G_3) is given in Appendix C (Figure C.2).

3.5.4 GPS devices download and data management

In the areas where the sampled transhumant herds grazed during the data collection period the GSM network coverage was poor and data transmission insufficient, hence GPS positions were predominantly stored in the backup memory. At the end of the data collection in May 2015 all of the collars were retrieved from the cattle. The collars were then shipped to the producer to manually download the stored data which were then sent as .csv files.

Along with the retrieval of the GPS devices the pictorial diaries (G_2) provided to the keepers escorting the animals were also recollected. The hard copies of the questionnaires carried out with the herdsmen and keepers (G_3) upon return from the transhumance were then transcribed into a pre-designed Microsoft Excel spreadsheet and stored as separate .csv files.

3.6 Ethical approval

The study design and sampling methodology for this study were authorized by the Cameroonian Ministry of Scientific Research and Innovation (MINRESI) and the Ministry of Livestock, Fisheries and Animal Industries (MINEPIA), and approved by the Cameroon Academy of Sciences. Approval was also obtained by the Veterinary Ethical Review Committee of the Royal (Dick) Veterinary School (University of Edinburgh) (ERC No: 28 14). All methods were performed in accordance with the relevant guidelines and regulations and informed consent was obtained from all subjects. Interviewers were trained to provide the information regarding the consent process to be communicated to the participants. Prior to interviewing, the study objectives, procedures and the content of the questionnaires were also explained to the participants in their local language if necessary and they were assured that the questionnaires and record data would be treated anonymously. Due to the chaotic nature of the sampling context the written consent was impractical and all the participants provided informed verbal consent recorded by the interviewer at the time of interview. This research project was funded by the University of Edinburgh through a Principal's Career Development Scholarship.

Chapter 4

Characterisation of the cattle trade system in central Cameroon

4.1 Introduction

4.1.1 Livestock marketing in Cameroon

As in most of the African continent, livestock trade in Cameroon consists mainly of live animals rather than trade in animal products. Livestock trade in Cameroon, and in particular of cattle, mainly occurs via multiple intermediate steps in the form of a trading point where the livestock market takes place. The role of livestock markets as hotspots for the dispersal of infectious diseases has been proved in diverse farming systems and in various regions of the world despite the diverse levels of organization of these markets (Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Rautureau et al. [2011]; Dean et al. [2013]; Fournié and Pfeiffer [2013]; Vallée et al. [2013]; Molia et al. [2016]). Therefore, understanding the characteristics and practices of livestock markets is key for a more informed management of animal health through the trading system.

Livestock trade in Cameroon involves transactions in conventional marketing infrastructures generally constructed and owned by the Government. Livestock markets are established points where herders, traders, butchers and other stakeholders involved in the livestock sector carry out central activities for the trade of animals, as well as networking, buying consumables and medicines for the herds and, in some markets, for the whole household.

At the market level, cattle on sale tend to mix together in the sale pen while the negotiations are taking place. Sales are negotiated directly between sellers and buyers or often by intermediaries, which mediate between cattle herders or between herders and traders. Traders, are important actors in the system that tend to acquire cattle in more rural markets and commercialise them along the trading chain towards the national or border markets. Usually the sales procedure involves the payment of taxes to the Government or the Municipality by both the seller and the buyer, once sale of the animals has been agreed. Hence, a better understanding about the habits of the stakeholders involved in this system could help the design of communication and/or training campaigns to increase awareness of the risks of introduction and dissemination of infectious diseases through cattle trading and how to possibly mitigate these risks through improving management practices.

Due to the structure of the trading chain, the transfer of live animals represents a critical aspect of cattle trade. Three types of animal transportation from production areas to livestock markets and between markets can be differentiated in Cameroon: trekking (on foot), road transportation (by trucks) and railway transportation (by train). Trekking of cattle conducted by herdsmen or keepers is, generally, the predominant way of moving cattle especially in livestock production areas, and still represents an alternative to truck or train transportation towards the main cattle markets of the country or to the border markets. Usually, in livestock production areas cattle are trekked to the livestock markets directly from the single households or grouped at the neighbourhood or village level before being walked to the market.

After the negotiations and the transactions have taken place at the market level cattle that are acquired by herdsmen are then taken back to the village level on foot to be introduced into the herd. Cattle acquired by traders are, instead, usually gathered and grouped together before being moved to other markets or to the slaughterhouse. The transfer towards another market can be on foot, by road or railway depending on the distance of the markets from tarred roads, on the financial resources of the traders and on security aspects. The degradation of pasturelands and the scarcity of water points along the trekking paths, represent one of the major challenges for the herdsmen and the animals during long treks. The expansion of agricultural crop production into new areas along these paths may also represent a source of conflicts between the herders and farmers (Pamo [2008]; Kelly et al. [2016]). All these constraints may increase the stress to the animals due to longer treks as well as raising the risks for the herdsmen and traders leading the cattle towards more remote and uncontrolled zones.

Transportation on trucks is, usually, carried out only between major markets across the country. It is quicker and safer for the herdsmen but often raises major issues for animal welfare, as well as for capital loss. The number of cattle loaded on trucks usually merely depended on the number of animals that needed to be transported to that destination and it was not uncommon for some cattle to reach the final destination injured. Additionally, depending on the distances to be travelled, deprivation of water and food during the transportation can also last for days with all the consequences for animal welfare and animal health that could arise.

Major pathogens heavily impacting cattle herds in Cameroon have been reported to be FMD, pateurellosis, contagious bovine pleuropneumonia (CBPP), lumpy skin disease (LSD), bovine dermatophilosis and tick-borne diseases (Awa and Achukwi [2010]). At the market level a visual veterinary inspection of the presented animals is carried out by the local veterinary services. Nevertheless, there is little published literature on the characteristics of livestock markets and of their implications for infectious diseases dissemination in Cameroon and in SSA in general.

Knowledge of the volumes of the cattle traded through the markets as well as of the animal characteristics is critical to better understand the role of livestock markets in this scenario. Information on the practices carried out at these markets and of the behaviours of the stakeholders involved in cattle trade is key for improving the understanding of this system. Ultimately, this information could help identifying the major gaps within the cattle trade system helping informing interventions for the improvement of animal health management in this system. Identifying these gaps would ideally provide indications for helping designing communication campaigns aimed at raising the awareness of the potential impact of management practices, both at market and herd levels, in reducing the risk of acquiring and spreading infectious diseases through the cattle marketing system. Eventually, raising awareness would also provide these stakeholders with the opportunity to participate in, and contribute to, surveillance strategies, particularly in what is currently referred to as “passive surveillance”, as for instance by routinely reporting on animal health information at the market level.

4.1.2 Objectives

The overall purpose of this chapter was to provide an overview of the context of the cattle marketing system in the study area based on primary data collected during this project. Obtaining a general picture of this system, including key information on volumes and characteristics of the traded animals, as well as describing the principal features of the cattle markets, would provide valuable information to identify the current major challenges and constraints in animal health management in this system. Simultaneously, better understanding of the habits of stakeholders involved in cattle trade would help identifying behaviours that increase (or decrease) the risk for the introduction and dissemination of infectious diseases through animal trade.

The first objective of this chapter was to characterise the key features of the cattle trade system in the study area. These features were, the volumes, the commercial value and the characteristics of the traded cattle in the Adamawa, West and North-West Regions and through the major markets in the southern part of the country (Yaoundé, Douala and Kye-ossi).

The second objective was to describe the main market management practices and their potential implications for animal health. Information on other species traded at the market, their interaction with cattle, localisation of the market in relation to transhumance routes and key infectious diseases affecting the traded cattle were collected for this purpose.

The third objective was to describe the livestock management practices of the stakeholders involved in cattle trade at the market level and identify practices that could represent risks for dissemination of livestock infectious diseases through cattle trade.

4.2 Materials and Methods

4.2.1 Study area and data collection (R_1, R_2, Q_1 and Q_2)

Cattle markets in the Adamawa, West and North-West Regions were included in this study as well as in the main urban centres of the country, in Yaoundé and Douala, and the border market of Kye-ossi were also sampled (see Section 3.2.2 of this Thesis). The data collection was carried out in 62 cattle markets between September 2014 and May 2015. At each cattle market data from the transaction records (R_2) were collected (see Section 3.3.1 of this Thesis). Semi-structured questionnaire-based interviews (Q_2) were carried out with the various stakeholders attending the marketing day using a convenient sampling methodology (see Section 3.3.3 of this Thesis). In addition, official trading reports (R_1) were collected at sub-Divisional offices of the MINEPIA and questionnaire-based interviews were carried out with the representative of the veterinary services (Q_1) competent for each market (see Section 3.3.1 and 3.3.2 of this Thesis).

4.2.2 Data processing

These diverse data collection strategies were then used separately or in combination in order to address the objectives of this chapter. The data originated from the official reports (R_1) and the transaction records (R_2), included the number of traded animals, their sex and age and their prices recorded in Central African Franc (CFA) and were used to describe the volumes and values of cattle trade across the study areas. As described in Section 3.3.1 the reports and records from the markets located in Douala and Kye-ossi, while reporting number, origins and destinations and animal type of the batches of traded cattle, did not consistently include the value of the transaction for each recorded batch and, therefore, this information was only obtained through the data collection approach described in the subsequent section of this chapter (Q_1).

In these records the traded cattle were classified in different classes according to their sex and their age reported in these documents. Cattle below the age of three are generally considered young animals and were therefore classified as heifers and young bulls depending on the sex. All animals above the age of three were considered as adult cows and bulls or, if castrated male animals, as steers.

The 62 questionnaires carried out with the veterinary service officials (Q_1) provided the source to describe the characteristics of cattle markets and the cattle management practices at this level (see Section 3.3.2). The questionnaire-based interviews carried out with other markets stakeholders (Q_2) (N= 591, see Section 3.3.3 and Table 3.2) provided information on herds management practices both at the herd level and at the market place. Information from the official reports and records (R_1, R_2) as well as from the questionnaires (Q_1) were used in order to classify the cattle markets within the study area.

All these data collection strategies aimed at gathering information relative to a 12 month period of observation, therefore, encompassing both the dry and rainy seasons. The durations of the seasons differ slightly across the study area. However, for the purposes of this study we can generally refer to the rainy season as between May and September while the dry season normally extends from October to April (Pamo [2008]).

4.2.3 Data analysis

A combination of simple descriptive and visual analytical approaches were applied to provide an overview of the state of the marketing system. The trends of traded cattle and relative price variation over the 12 months of study were assessed.

Ratios of the absolute number of cattle traded per month to the mean number of traded cattle per month were calculated to assess the relative variation of traded cattle over the year.

$$\rho_c = \frac{x_{ij}}{\bar{x}_i} \tag{4.1}$$

where:

ρ_c	the ratio of mean traded cattle
x_{ij}	the absolute number of traded cattle in region i per month j
$\bar{x}_i$	the mean number of monthly traded cattle in region i

Ratios of the mean price per head of cattle per month to the overall mean price over the year in each Region were also computed to evaluate the relative variation of the cattle price.

$$\rho_p = \frac{x_{ij}}{\bar{x}_i} \tag{4.2}$$

where:

ρ_p	the ratio of mean cattle price
x_{ij}	the mean price per head in region i per month j
$\bar{x}_i$	the mean price per head in region i over the year

The proportions of the type of traded cattle were then examined to highlight eventual differences in the populations of cattle on the market. Subsequently, the combination of volumes and prices per animal type were visualised over the twelve-month period to summarise and highlight regional differences.

Hierarchical, or nested, clustering technique was used to identify groups of markets with similar characteristics based on 3 types of information: *(i)* the size of the market, given by the total number of traded cattle over a 12-month period, *(ii)* the mean price of traded cattle over a 12-month period and *(iii)* the mean number of stakeholders attending a marketing day (including herders, traders and butchers). Hierarchical clustering analysis computes the proximity, or distance, matrix between markets. Merging the two closest clusters, updates the proximity matrix and merges again the two closest clusters until only one cluster remains (Tan Pang-Ning, Steinbach Michael [2006]). There are different approaches to measure the distance between clusters and therefore identify the closest clusters. In this study the Ward's method was applied because tends to create compact clusters of small sizes being particularly conservative in identifying distances, and therefore differences, between clusters increasing the confidence regrading differences identified between these clusters (Murtagh and Legendre [2014]).

All analysis and graphics were performed in the R statistical software (R Core

Team [2013]) (version 3.2.3) using the *hclust*, *raster*, *rgdal* and *ggplot2* packages.

4.3 Results

4.3.1 General trends of the cattle trade system (R_1, R_2 *and* Q_1)

Records of a total of 351,345 cattle traded between the 1st of September 2013 and August the 31st 2014 were collected within the 62 cattle markets across the study area (see Table 3.1 of this thesis). A total of 62 questionnaires were administrated to officials of the veterinary services and 591 questionnaires were conducted with other market stakeholders (herders, traders and butchers) (see Table 3.2 of this thesis).

Figure 4.1 shows the overall distribution of the volume of traded cattle across the whole study area over the year and the fluctuation of the mean price per animal. Across the entire study area, the number of traded cattle per month increased in the rainy season, with the exception of September when the number of traded cattle dropped (Figure 4.1). Nevertheless, the trading peak was registered in December, during the dry season, when 38,563 heads of cattle were traded (0.26 times higher that the monthly mean of 30,556). Overall, the volume of cattle sold and bought per month during the dry period was smaller, reaching the minimum in February with 25,154 head of cattle. Similarly to the trade volume, the mean price per animal peaked in December with a mean value of 416,200 CFA for each traded cattle (0.05 times higher that the yearly mean of 393,460) (Figure 4.1). Contrary to the trend observed in the volumes of traded cattle, the mean price

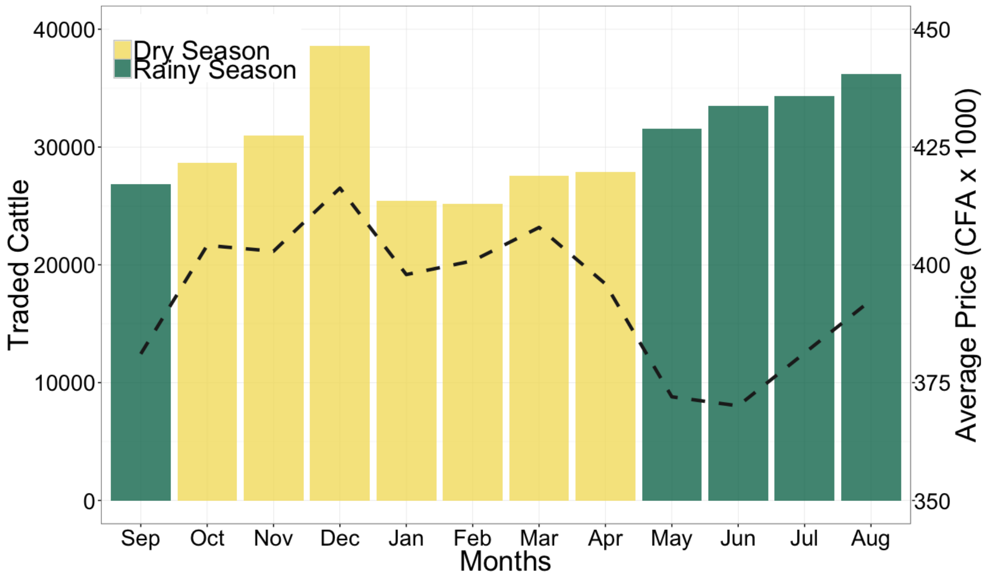

Figure 4.1: **Monthly trends of traded cattle and of the mean price per head in the entire study area.**
The months of the observation period between Sep 2013 and Aug 2014 are displayed on the x axis: yellow bars refer to months during the dry season and green bars to months during the rainy season. The y axis reports the absolute number of traded cattle per month. The dashed grey line refers to the mean price per head of cattle in CFA (x1000) reported on the z axis.

per head across the whole study area was relatively lower during the rainy season compared to the dry season, reaching the lowest level in June (370,000 CFA) (0.06 times lower that the yearly mean of 393,460) (Figure 4.1).

4.3.2 Regional volumes and commercial values of traded cattle (*R_1, R_2 and Q_1*)

The three main study Regions showed differences with regard to the trends of both the volumes and prices of the traded cattle (Figures 4.2 and 4.3). The highest monthly trading volume was registered in December, during the dry season, across most of the study area with the exception of the Adamawa Region and the markets located in Yaoundé and Kye-ossi (Figure 4.2). In particular in the Adamawa Region the trading peak was registered in June and continued in July and August, while December 2013 registered only the 4th highest trading volume of the period under observation. This Region was also the area with the highest mean number of traded cattle per month (˜8,000 animals/month) (Figures 4.2 and 4.4).

In the North-West Region a mean of about 4,800 head of cattle were traded per month, while in the West Region the trading volume was smaller with a mean of about 2,600 cattle every month. Big urban markets in Douala and Yaoundé are very important commercial hubs trading a monthly mean of, respectively, 7,500 and 5,800 heads of cattle (Figures 4.2 and 4.4).

In the Kye-ossi market, in the extreme South of the country only a mean of less than 1,000 cattle per month were traded (Figures 4.2 and 4.4). Despite the small number of traded animals in this market, the mean price per animal was the highest of the entire study area (552,300 CFA/animal, SD=14.4, N=9,791) (Figures 4.3 and 4.5). In the markets of Douala and Yaoundé the mean price per cattle was

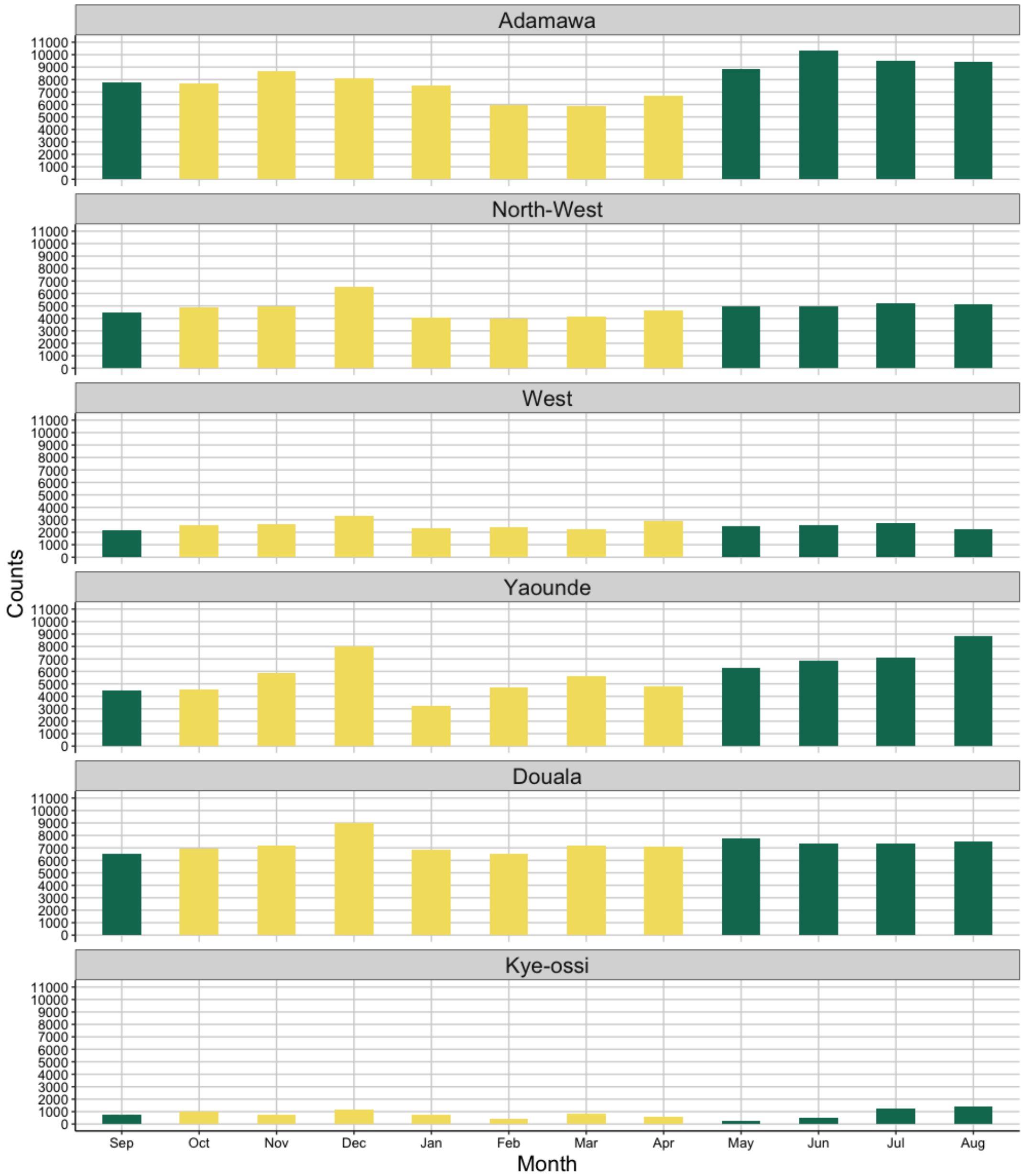

Figure 4.2: **Distribution of the volumes of traded cattle across the study area.**

On the y axis the counts of traded cattle and on the x axis the month for the period of observation between September 2013 to August 2014 (yellow bars refer to months during the dry season and green bars to months during the rainy season). The study area included the main cattle production Regions (Adamawa, West and North-West) and the single markets visited in the main consumption zones (Yaoundé, Douala and Kye-ossi).

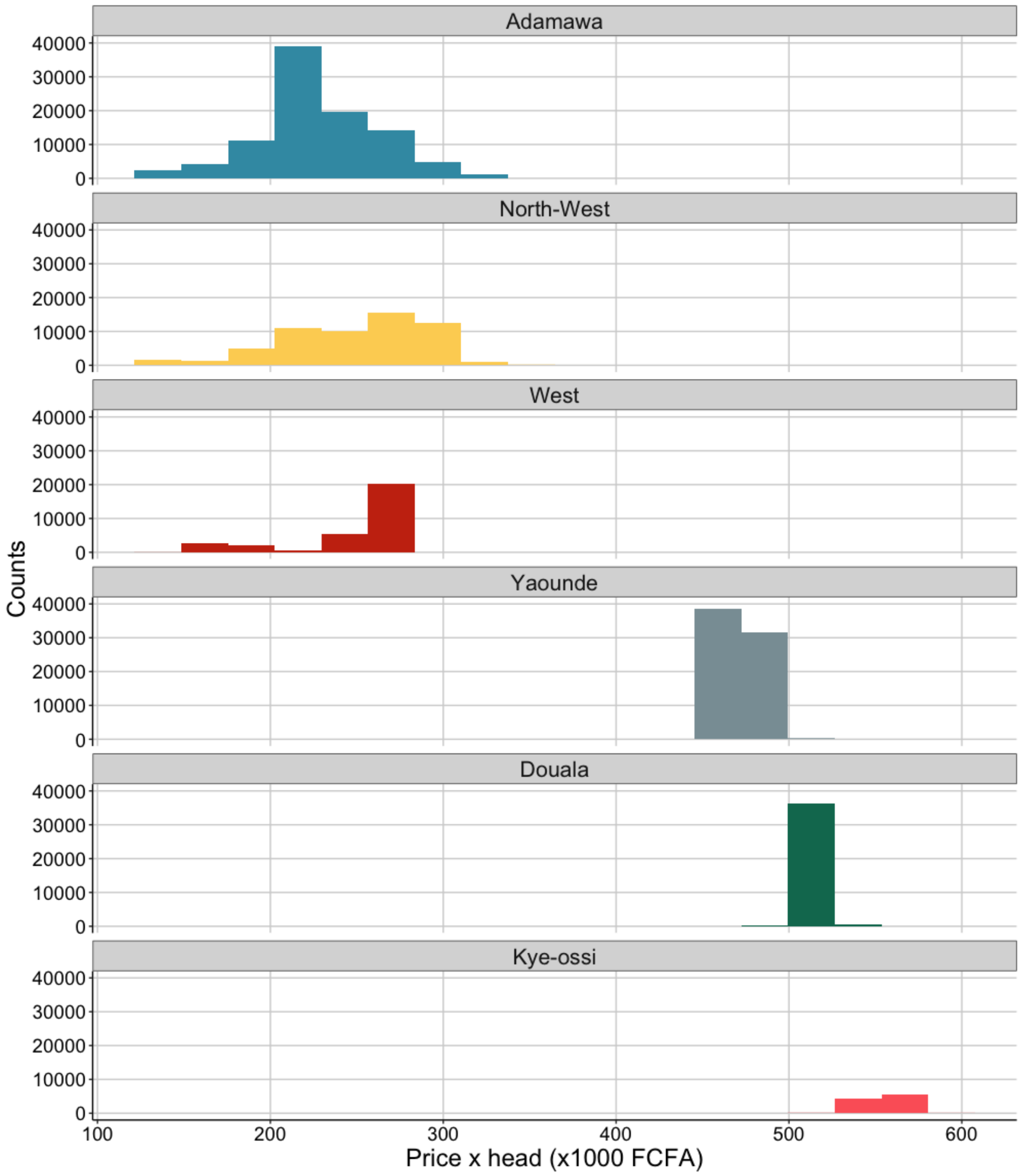

Figure 4.3: **Distribution of the price per head across the study area.** On the y axis the counts of traded cattle and on the x axis the price per head in the study area, including the main cattle production Regions (Adamawa, West and North-West) and the markets visited in the main consumption and bordering zones (Yaoundé, Douala and Kye-ossi).

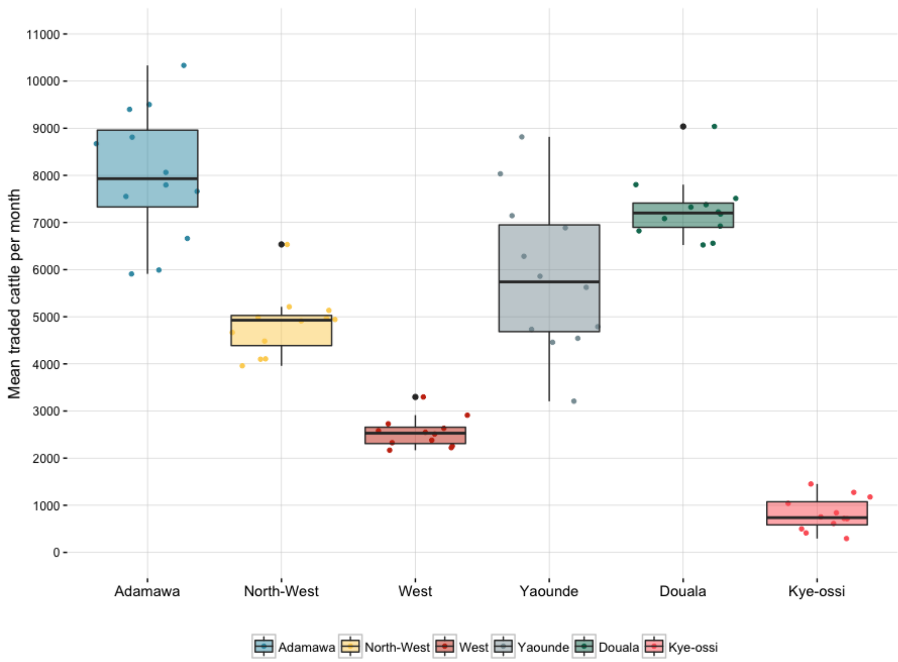

Figure 4.4: **Number of traded cattle per month across the study areas (between Sep 2013 and Aug 2014).**
Boxplot of the number of traded cattle per month and on the x axis are displayed the 3 main study areas (Adamawa West and North-West Regions) and the single markets visited outside these 3 areas (Yaoundé, Douala and Kye-ossi). For each box the dots refer to the mean traded cattle each month, the upper and lower “hinges” correspond to the 1st and 3rd quartiles (the 25th and 75th percentiles) and the horizontal line to the median value over the year.

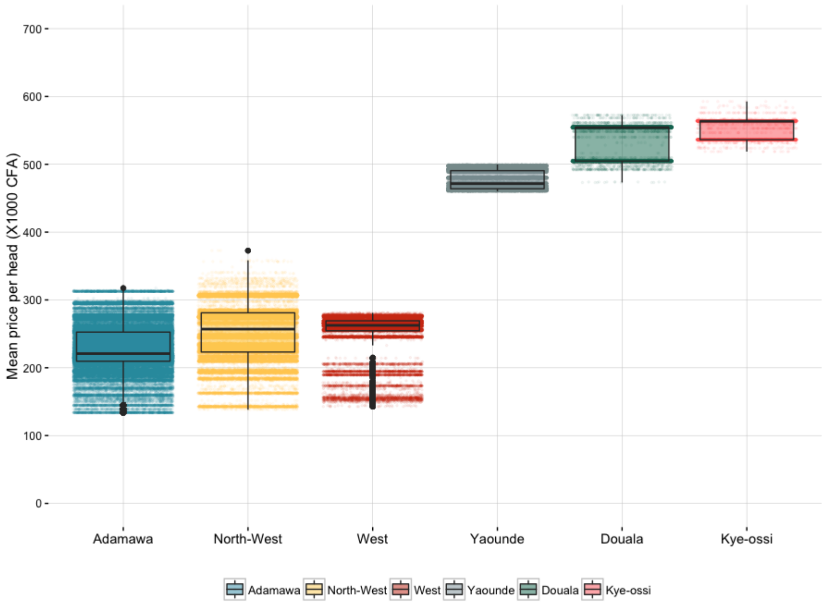

Figure 4.5: **Price per head of cattle across the study areas (between Sep 2013 and Aug 2014).**
Boxplot of the price per head of individual traded cattle and on the x axis are displayed the 3 main study Regions (Adamawa, West and North-West) and the single markets visited outside these 3 areas (Yaoundé, Douala and Kye-ossi). For each box the dots refer to the price per cattle, the upper and lower “hinges” correspond to the 1st and 3rd quartiles (the 25th and 75th percentiles) and the horizontal line to the median value over the year.

slightly lower, 533,700 (SD=25.6, N=87,363) and 476,900 (SD=13.1, N=70,369) CFA/animal, respectively. Cattle production Regions showed a markedly lower mean price per head (Figure 4.3). In the North-West Region cattle were sold at a mean price of 251,600 (SD=5.8, N=58,015) CFA/animal, in the Adamawa and West Regions at a mean price of 226,900 (SD=16.6, N=96,355) and 249,100 (SD=5.7, N=30,562) CFA/animal, respectively.

The analysis of the ratio of the absolute number of cattle traded per month to the mean number of traded animals per month in each Region, showed some relative differences across the study areas. In the North-West and West Regions the relative trading volume had similar trends and were overall consistent across the year showing, nonetheless with a peak in December (Figure 4.6A). In contrast, in the Adamawa Region the relative trading volume showed a more pronounced seasonal trend with an increase of the relative volume of traded cattle between May and August and a decrease between December and May (Figure 4.6A).

Also the ratio of the mean price of traded cattle per month to the mean price per head over the year varied across these three Regions. Similarly to the traded volumes, the relative mean cattle price in the North-West and West Regions was stable overall showing very little fluctuation compared to the mean yearly price over the 12 months of observation. The relative monthly mean price per head in the Adamawa Region, by the contrary, showed a possible seasonal pattern. This trend was in contrast to the pattern showed by the volumes of traded cattle, increasing during the rainy season and decreasing in the dry season: despite the lower relative variability in comparison to the trading volume, the relative mean price was higher from the beginning of the dry season (September 2013) until January when it started decreasing reaching the lowest level in April when it started to slowly increase again.

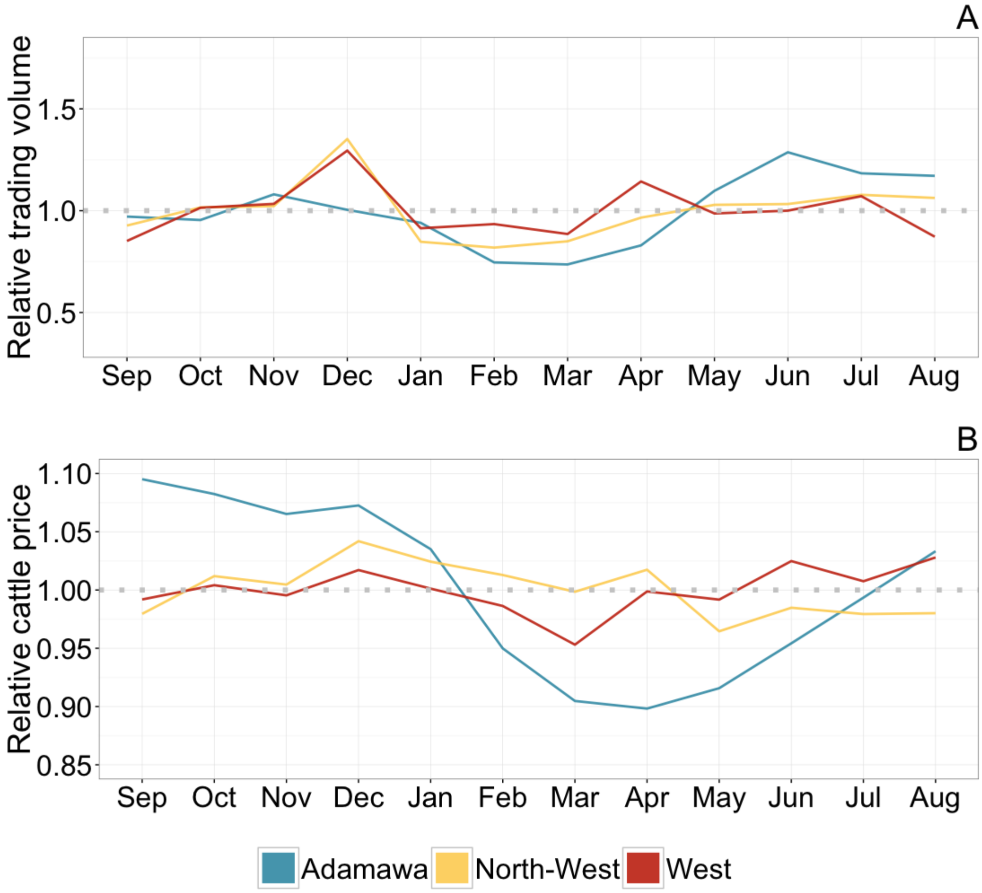

Figure 4.6: **Relative cattle trade volumes and mean price per head in the Adamawa, North-West and West Regions.**
A: monthly ratio of the mean number of cattle traded per month to the mean number traded over the year. B: monthly ratio of the mean price per head per month to the mean price per head per year. The dotted line represents the null value (1:1 ratio). The period of observation spans between September 2013 and August 2014.

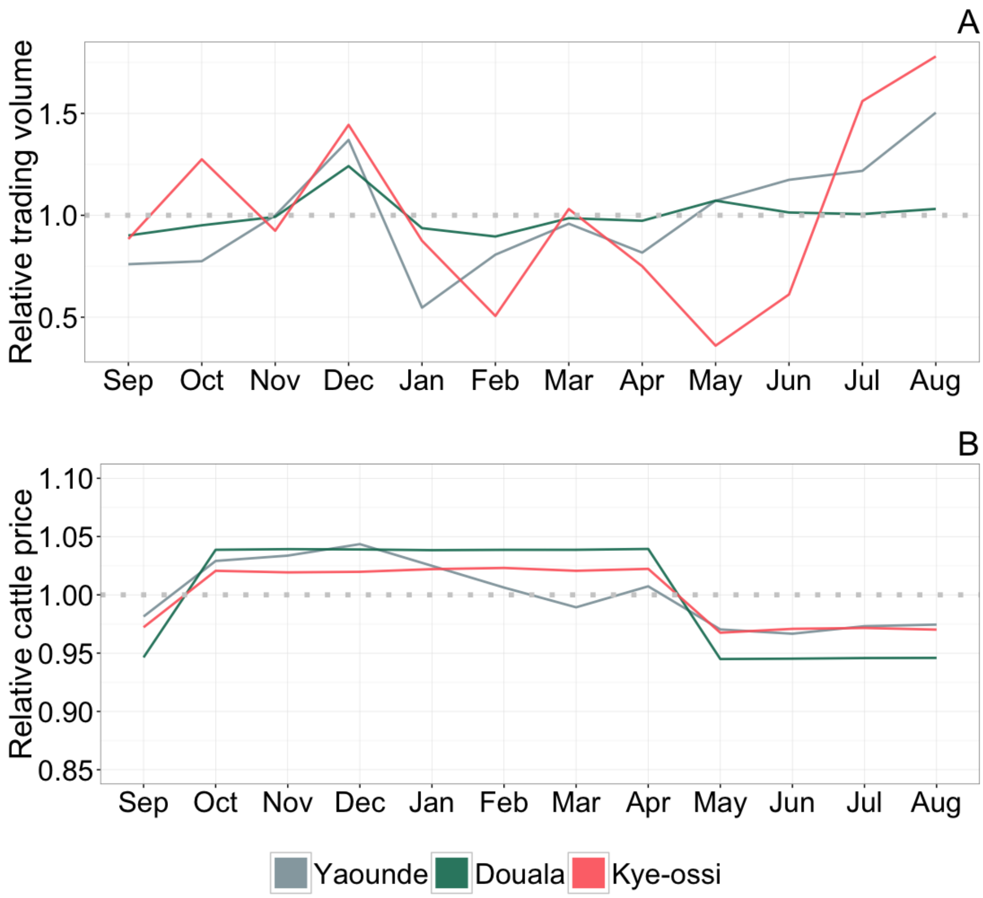

Figure 4.7: **Relative cattle trade volumes and of the mean price per head in the the markets in Yaoundé, Douala and Kye-ossi.**
A: monthly ratio of the mean number of traded cattle per month to the mean number traded over the year. B: monthly ratio of the mean price per head per month to the mean price per head per year. The dotted line represents the null value (1:1 ratio). The period of observation spans between September 2013 and August 2014.

Overall the relative volume of traded cattle in the Adamawa Region ranged between 0.76 and 1.32, therefore showing a relative variability of 56% compared to, respectively, the 29% and 23% in the North-West and West Regions (Figure 4.6A). The relative variability of the mean price per head over the year across these three Regions, showed an overall range of fluctuation of about 20% in the Adamawa Region (0.89 - 1.10) and less than 10% in both the North-West and the West Regions (0.96 - 1.05) (Figure 4.6B).

Douala showed a very stable supply of cattle across the year, with a slight relative increase in December (Figure 4.7A). Conversely, the relative trading volume in the markets of Yaoundé and Kye-ossi were more volatile. In both these markets the relative mean number of traded cattle peaked between June and August and then increased again in December. In the Kye-ossi market, in particular, the relative variation of the volume of traded cattle ranged between 0.4 and 1.7 (130% variability), while in Yaoundé market it fluctuated between 0.55 and 1.45 (90% variability) (Figure 4.7A).

All these 3 markets (Douala, Yaoundé and Kye-ossi) showed very similar trends of the relative mean monthly cattle price across the year (Figure 4.7B). Overall the range of variation was about 10%, displaying a clear seasonal pattern with a decrease in the relative mean monthly cattle price during the dry season (Figure 4.7B).

4.3.3 Types of animals traded through the market system and regional variations (*R_1 and R_2*)

There were some relevant regional and market differences in the types of traded cattle (Figures 4.8 and 4.9). The North-West traded predominantly adult cows, bulls or steers with these categories accounting for almost 85% of the traded volume in this Region (Figure 4.8). This predominance of adult cattle within the trading system was even more evident in markets located in the high animal consumption areas of Yaoundé, Douala and Kye-ossi where only between 5 to 10% of the traded animals were young cattle (Figure 4.9). On the contrary, heifers and young bulls accounted for about 50% of the cattle traded in markets located in the Adamawa Region, while in the West Region young animals were around 30% of the overall traded volume (Figure 4.8).

Specifically, in the North-West Region bulls accounted for about 65% of the overall traded cattle, with about 15% cows, 5% steers and between 7-8% for both the heifer and young bull categories. These proportions were consistent across the year in the North-West Region.

In the West Region, in comparison, almost 45% of cattle traded through the market system were cows, with about 25% bulls and 20% young bulls and almost 10% heifers with only a very small percentage of steers. These proportions were stable over the year, with only a slight increase in the proportion of adult animals traded between October 2013 and February 2014.

Similarly, in the Adamawa Region the proportion of bulls and cows slightly increased towards the end of the year peaking in December. In this Region young animals on the market peaked, instead, between April and May. Overall, bulls and cows accounted approximately for about 25% of the traded animals each, with young bulls and heifers representing respectively between 25-30% and 10-15% of the animals on the market, and steers being only less of the 5% of the traded animals (Figure 4.8).

In the cattle markets of Yaoundé, Douala and Kye-ossi bulls represented the absolute majority of traded animals, followed by cows and then steers (Figure

4.9). This pattern became even more pronounced during the second part of the year when almost the entierity of the cattle traded at the market were adult.

Figures 4.10 and 4.11 summarise the Regional differences in types of traded cattle, their volumes and proportions as well as their mean price per head. These figures confirm that the livestock marketing system in the Adamawa and West Regions clearly shows a more heterogeneous supply of cattle types on the market, with young and adult animals both representing consistent proportions of traded animals. Conversely, cattle traded in the North-West Region, and even more in the markets of Douala, Yaoundé and Kye-ossi were almost entirely adult animals, particularly adult bulls. Figures 4.10 and 4.11 also summarise the differences in mean prices per class of cattle highlighting again, as shown in Figure 4.5, that the mean price of cattle at the market is lower in cattle production areas.

4.3.4 Classification of the cattle markets (R_1, R_2 and Q_1)

Cluster analysis was based on 3 types of information: *(i)* the size of the market, given by the total number of traded cattle over a 12-month period (R_1 and R_2), *(ii)* the mean price of traded cattle over a 12-month period (R_1 and R_2) and *(iii)* the mean number of stakeholders attending a marketing day (Q_1). The four main sub-clusters identified by the hierarchical clustering analysis were used to classify four classes of markets whit close characteristics: primary, regional, sub-regional and local (Figure 4.12 and Table 4.1). Within each of these four clusters further partitioning, or nesting, can then be identified. The primary markets class included only 3 markets, which were two urban markets and a frontier market in the southern regions of Cameroon. A total of 10 markets in the Adamawa Region, 2 in the North-West Region and 1 in the West Region were classified as regional markets. The sub-regional market class included 16 markets in the Admawa

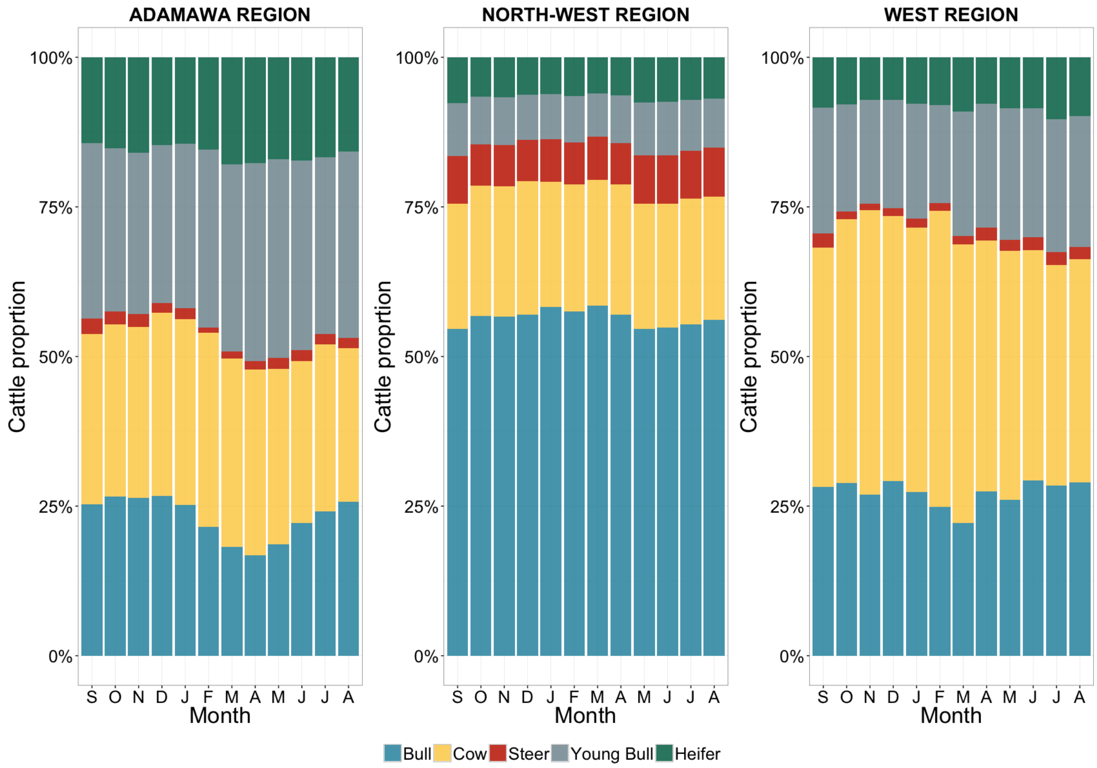

Figure 4.8: **Types of cattle traded across the three main study Regions.** On the x axis are the months of the year while the y axis are the proportions over the total number of traded cattle that month. The period of observation spans between September 2013 and August 2014.

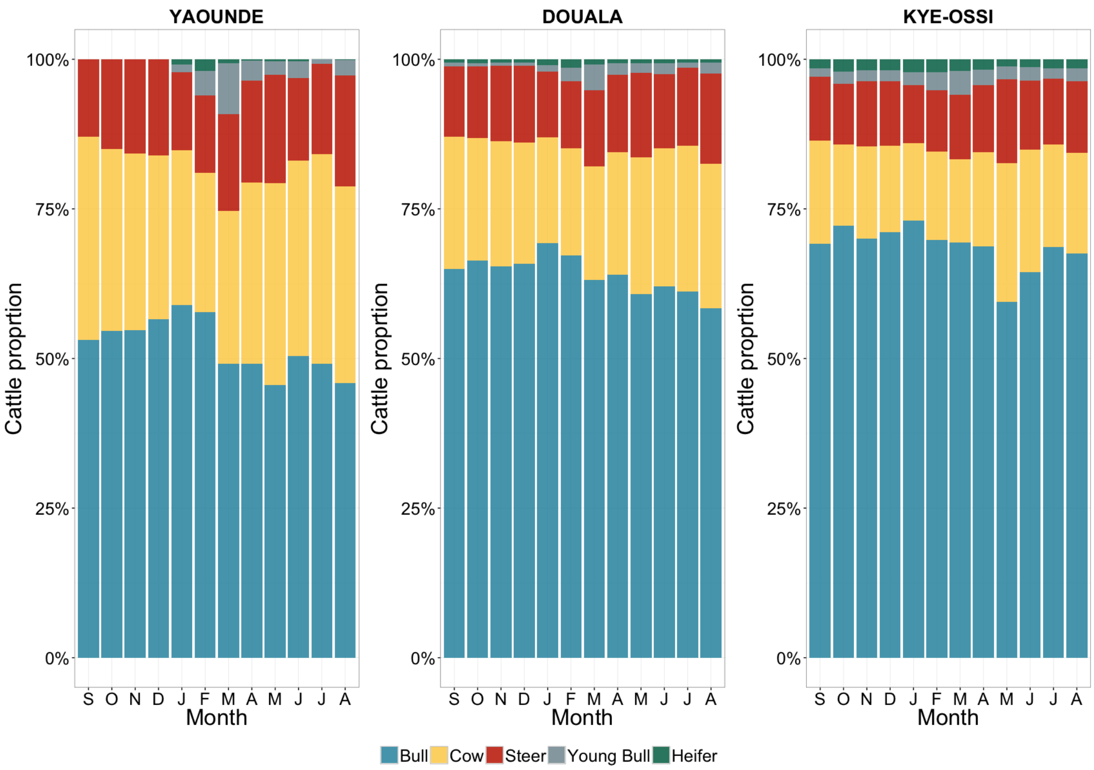

Figure 4.9: **Types of cattle traded within the markets of Yaoundé, Douala and Kye-ossi.**
On the x axis are the months of the year while the y axis are the proportions over the total number of traded cattle that month. The period of observation spans between September 2013 and August 2014.

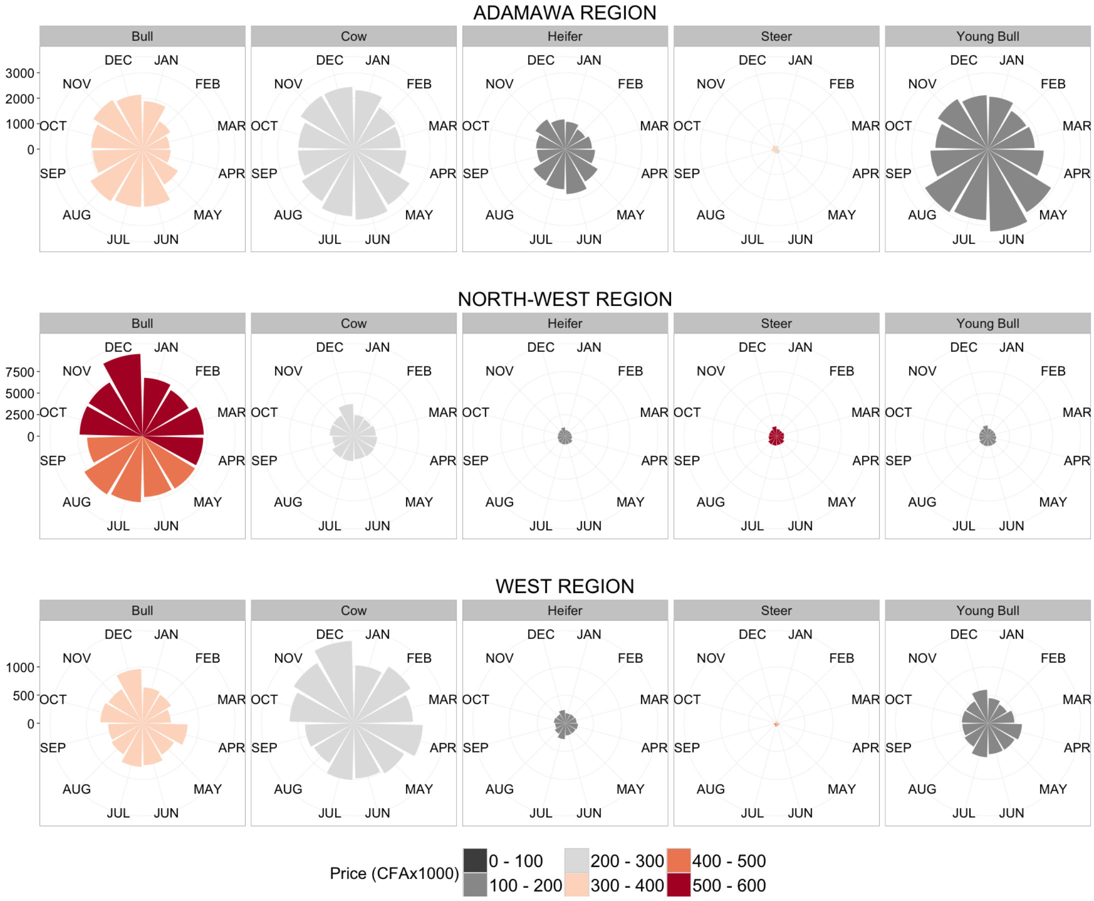

Figure 4.10: **Types of traded cattle per month and their mean price per head/month in the three main study Regions.**
The size of each petal of the plot is proportional to the number of cattle traded in that specific month for each of the five categories of cattle. The color of the petal refers to the mean price per head of that specific cattle category for each month (price in CFA x 1000). The y axis indicating the volume of traded cattle is not in scale because the purpose of this plot was to give an image of the different types of traded cattle in the different areas, their monthly fluctuations and their mean price and not an image of the absolute volumes. The period of observation spans between September 2013 to August 2014.

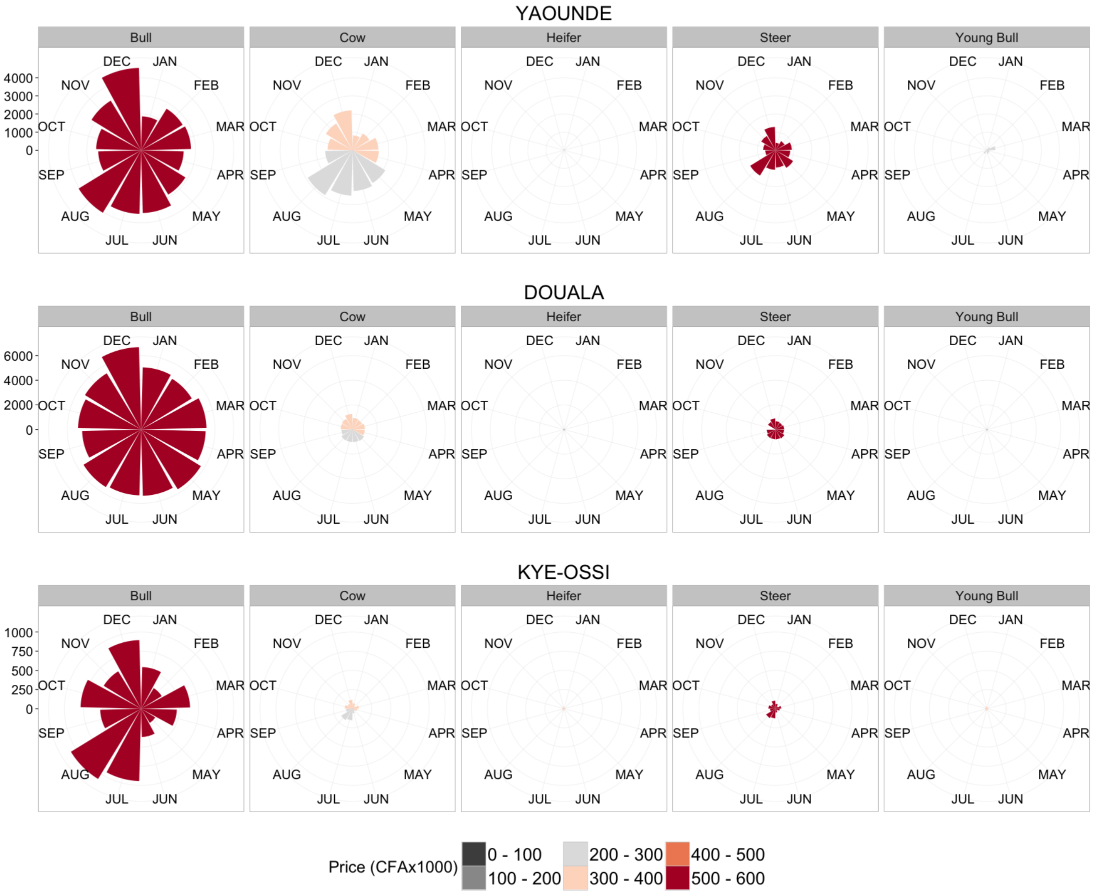

Figure 4.11: **Types of traded cattle per month and their mean price per head/month within the markets of Yaoundé, Douala and Kye-ossi.** The size of each petal of the plot is proportional to the number of cattle traded in that specific month for each of the five categories of cattle. The color of the petal refers to the mean price per head of that specific cattle category for each month (price in CFA x 1000). The y axis indicating the volume of traded cattle is not in scale because the purpose of this plot was to give an image of the different types of traded cattle in the different areas, their monthly fluctuations and their mean price and not an image of the absolute volumes. The period of observation spans between September 2013 to August 2014.

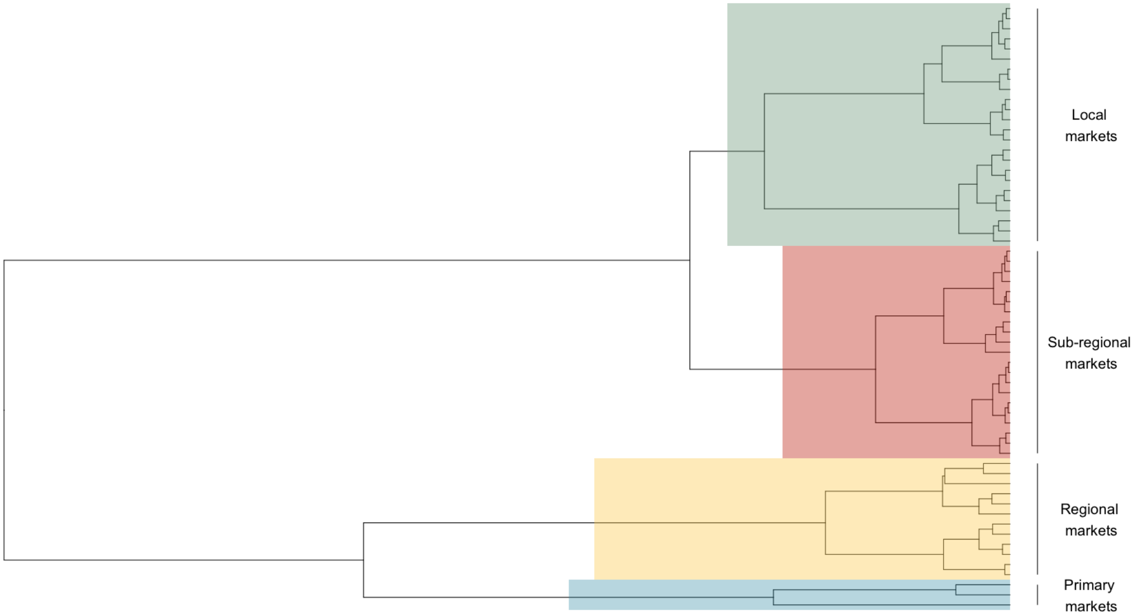

Figure 4.12: **Hierarchical cluster analysis of cattle markets within the study area.**
Four major classes of markets were identified through clustering analysis, here highlighted by the four coloured quadrants. The green quadrant includes local markets, the red one sub-regional markets, the yellow regional markets and the blue primary markets.

Region and 8 in the North-West Region. Local markets was the class with the greatest number of markets: 10 in the Adamawa Region, 12 in the North-West Region and 5 in the West Region. Examples and images of markets belonging to each of the identified classes are shown in Figure 4.13. The geographical locations of the different classes of markets are plotted in Figure 4.14.

4.3.5 Other livestock species present at the marketing place (Q_1)

In some cases cattle were not the only livestock traded at the market locations. This was particularly the case in the Adamawa Region where in almost 70% of

Table 4.1: Classes of cattle markets across the study area based on hierarchical clustering.

Market Class	Region	Markets Name	Mean cattle traded per year	Mean cattle price (CFA)	Mean number of stakeholders
Primary	Central Littoral South	Yaoundé Douala Kye-ossi	55,836 (9792 - 87347)	512,000 (476,000 - 536,000)	156 (95 - 190)
Regional	Adamawa	Ngaoundere, Ngaoundal, Tello, Banyo, Ngaoui, Likok, Samba Mbang Foulbe, Nyambaka	7,532 (1,395 - 19,498)	242,500 (202,000 - 311,000)	154 (105 - 223)
	North-West	Bamenda, Takija			
	West	Foumban			
Sub-Regional	Adamawa	Alme, Libong, Dir, Meiganga, Margol, Mayo Baleo, Dibi, Mbanti Katarko, Kognoli, Garga, Mayo Darle, Martap, Galdi	2,720 (1,066 - 6,528)	220,400 (162,000 - 257,000)	87 (65 - 200)
	North-West	Misaje, Binshua, Binka, Dumbu, Sabongari, Esu, Wum, Bafut			
	West	-			
Local	Adamawa	Mbe, Dang, Dangfili, Djalingo, Lougga, Belel, Beka Gotto, Tourningal, Sambo Labo	1,529 (283 - 3,863)	223,300 (142,000 - 333,000)	42 (22 - 60)
	North-West	Kimbi, Subum, Ntumbaw, Mbiame, Weh, Wainamah, Acha Tugi, Fundong, Lassin, Saje-Babungo, Tingume-Babungo, Konene			
	West	Tayandi, Bafang, Bangambi, Maloua, Ngon-Kham			

[Note] Mean cattle traded and mean cattle price per market refer to a 12 month period (September 2013 to August 2014). Mean number of stakeholders refer to the mean number of stakeholders participating in a marketing day (herders, traders, butchers) - In brackets are reported the ranges of the means of traded cattle for each class, of the mean prices of cattle per class, and of the mean number of stakeholders.

Local market: Konene in the Boyo Division of the North-West Region
Cattle are grouped in the selling pen since the beginning of the marketing day. Any loading/unloading point is present at the market and all the traded cattle arrive at and leave from the market walking.

Figure 4.13: **Examples of local cattle markets classes across the study area.**

Sub-regional market: Martap market in the Vina Division of the Adamawa Region

Cattle are grouped in the selling pen since the beginning of the marketing day. Negotiation are taking place both inside and outside the sale pen. Any loading/unloading point is present at the market and all the traded cattle arrive at and leave from the market walking.

Figure 4.14: **Examples of sub-regional cattle markets classes across the study area.**

Regional market: Foumban in the Noun Division of the West Region
Cattle are grouped together since the beginning of the marketing day but any selling pen is present at the site. After the negotiations have been agreed and the taxes payed to the municipalities and veterinary services traded animals are moved to their destinations either on foot or by truck using the loading points. on the same day of the transaction.

Figure 4.15: **Examples of regional cattle markets classes across the study area.**

Primary market: Yaoundé market in the Mfoundi Division of the Centre Region

Cattle arrive on foot at the marketing area but have reached the city mostly either by truck or by train and have been unloaded previously of arriving the market place. The market is held 5 days a week, however the main marketing day is at the beginning of the week on Mondays. As in the other classes of markets, cattle are grouped together since the beginning of the day and remain in sell pen until negotiations are agreed, taxis are payed and official recordings have been carried out. Most of these cattle will be destined for human consumption in Youandé and a minor proportion will be traded towards the South Region (e.g. towards the Kye-ossi market).

Figure 4.16: **Examples of primary cattle markets classes across the study area.**

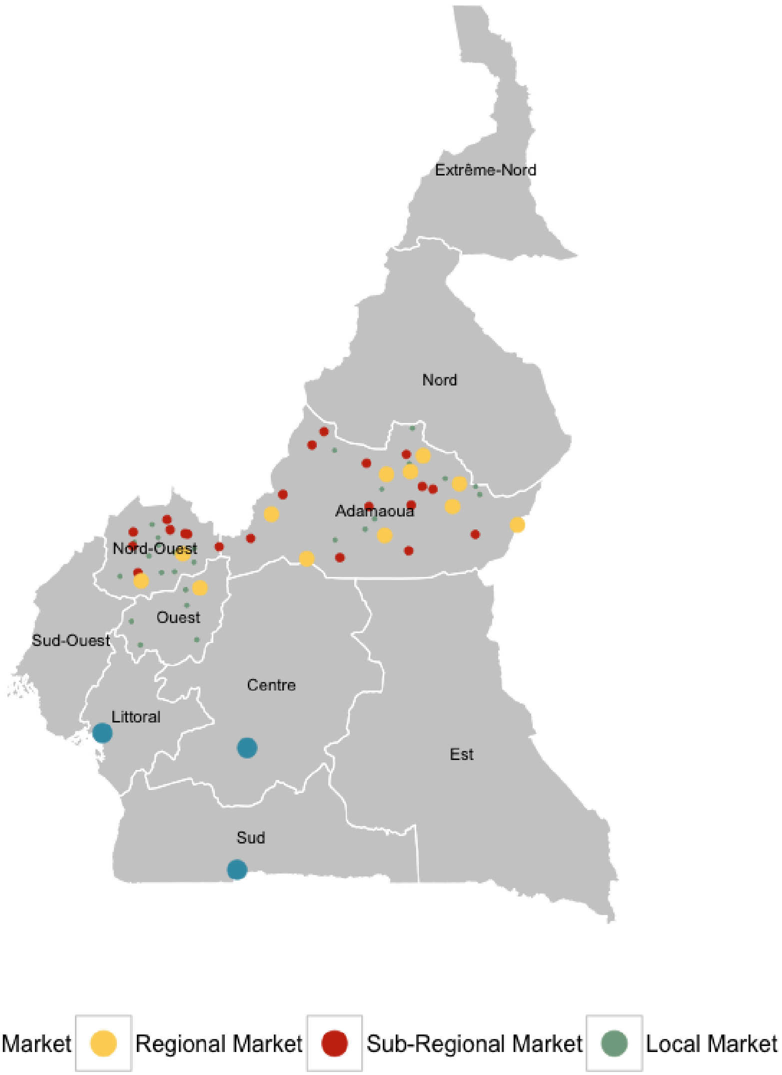

Figure 4.17: **Locations and classes of the markets within the study area.** Both the colours and the sizes of the dots refer to each of four classes of markets: bigger blue dots to primary markets, intermediate yellow dots to regional markets, small red dots to sub-regional markets and smaller green dots to local markets.

the markets sheep were also reported to be present at the market (Figure 4.15). However, only in less than 10% of the total markets sheep were actually sold in the same sale pens, therefore, mixing together with the cattle. In the Adamawa also poultry and goats were sold at markets, in 42% and 47% of the cases, respectively, but only rarely were actually mixing in the sale pen with cattle (9% and 3% of the markets) (Figure 4.15).

The North-West Region showed a very different pattern where sheep were traded in less than 20% of the markets. However, as in the Adamawa, sheep were sold in the sale pens along with cattle only about 10% of the total markets. Goats were also sold in about 15% of the markets and in about 1/3 of these markets were reported to mix with cattle. Poultry were traded in less than 5% of the markets, always in the same selling areas with cattle.

In the West Region sheep were sold in more than 60% of the markets, while goats and poultry in 18% of the markets, in both cases. Nevertheless, these other livestock never mixed in the sale pens with cattle (Figure 4.15).

In the markets located in the high human consumption areas of Douala, Yaoundé and Kye-ossi no other livestock species than cattle were reported being traded.

4.3.6 Reported diseases of traded cattle (Q_1)

A range of various livestock diseases affecting traded cattle through the marketing system were mentioned by the veterinary officials during the questionnaire-based interviews (Q_1). Dermatophilosis and FMD were consistently the most commonly reported infectious diseases across the study area (Figure 4.16). In the Adamawa Region the most commonly reported disease was FMD (30% of the markets) followed by dermatophilosis (25%) and trypanosomiasis (17%). A

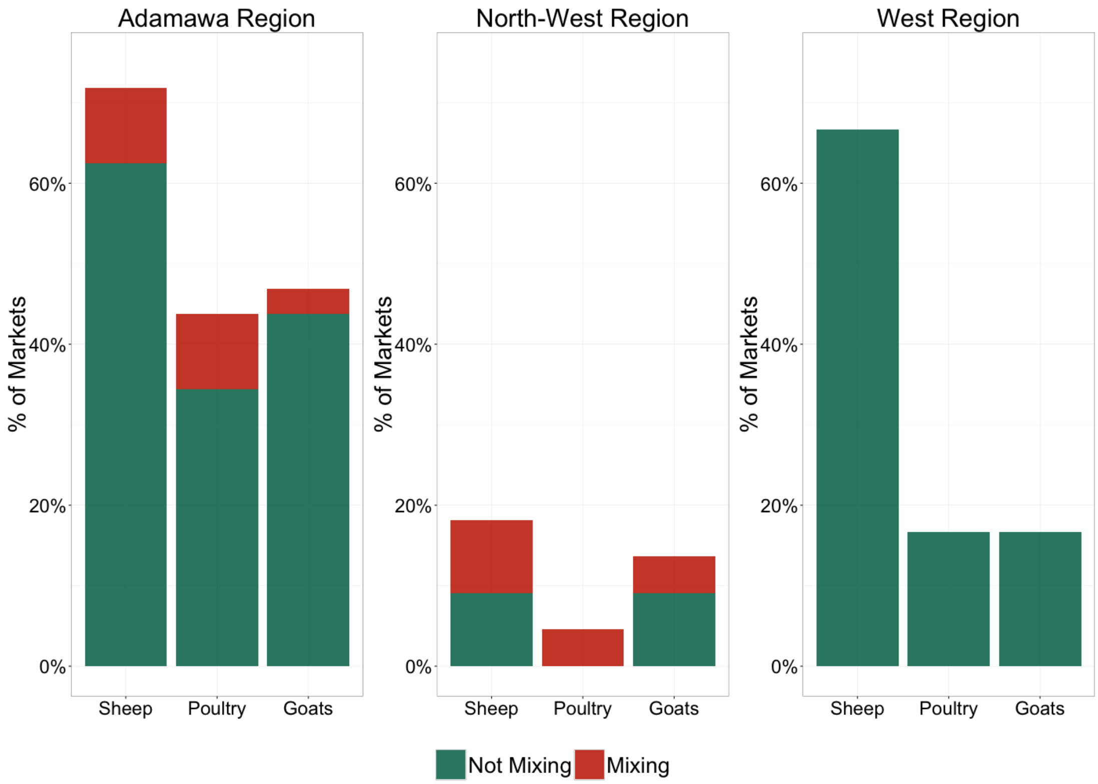

Figure 4.18: **Livestock species, other than cattle, traded at cattle markets within the three main study Regions.**
The x axis reports the other livestock species traded at the market level in three main study regions On the y axis the green colour refers to the percentages of markets where cattle and the other reported livestock are traded in the same market but do not mix in the sales pen. The red colour, by contrary, refers to the percentages of markets where the animals are sold in the same sales pen, therefore mixing with cattle.

Note no other livestock species were traded at the urban markets in Yaoundé, Douala and Kye-ossi.

similar situation was reported in the West Region where FMD was the most commonly reported disease (27%) followed by dermatophilosis (22%) and trypanosomiasis (17%). In the North-West, by comparison, dermatophilosis was the most reported (32%), followed by FMD (20%) and piroplasmosis (18%). However, a number of other infectious diseases and health problems were reported affecting traded cattle as shown in Figure 4.16.

When comparing the different classes of markets with regards to the reported animal health problems and infectious diseases, a relatively consistent distribution of reported diseases was observed between the different market classes (Figure 4.17). Dermatophilosis and FMD were consistently the most reported diseases, nevertheless, while dermatophilosis was the most commonly reported in local and sub-regional markets, FMD was the most reported in regional and primary markets.

4.3.7 Market locations in relation to transhumant zones (Q_1)

Across the three main study Regions the proportions of markets located within areas from where the cattle herds are undertaking seasonal transhumance, or that can be defined as the origin of transhumant herds, were consistent (Figure 4.18). In the Adamawa Region 91% of the markets were located in zones from where cattle herds are known to move for transhumance during the dry season, while this percentage was 85% in the North-West Region and 81% in the West Region.

A proportion of these markets were also located within transhumant zones and were, therefore, a transhumant destination for cattle herds coming from other areas. In the Adamawa only 4% of the markets were located in areas considered

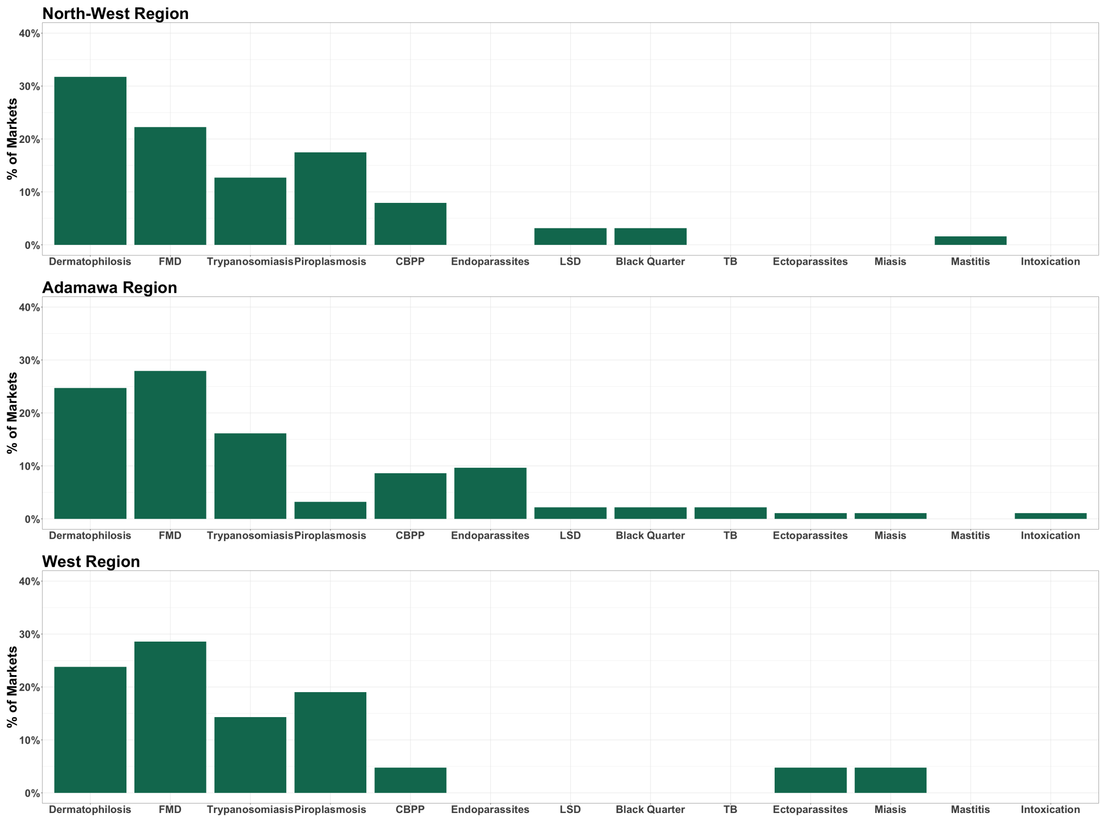

Figure 4.19: **Major cattle health problems reported at market level within the study area.**

For each Region the reported health problems affecting traded cattle are displayed on the x axis. The y axis indicates the percentage of markets where each specific disease was reported as one of the three main cattle health problems affecting the traded cattle.

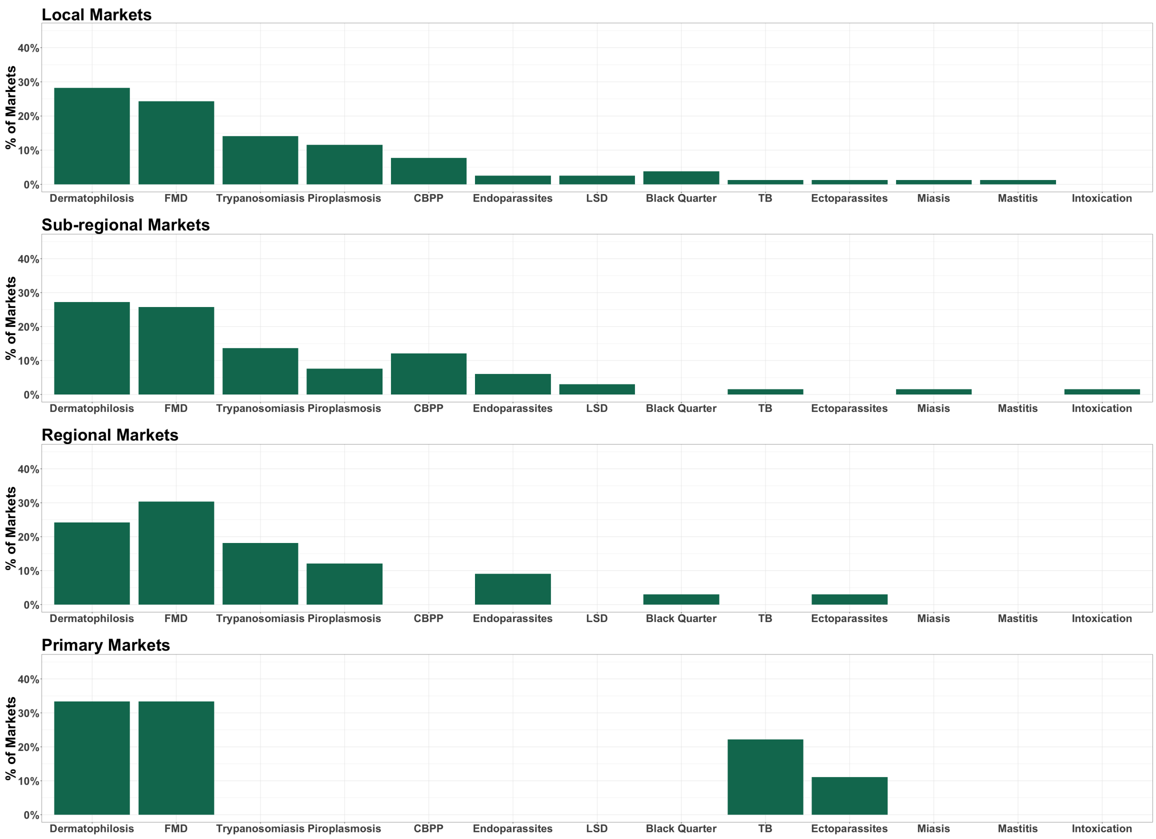

Figure 4.20: **Major cattle health problems reported in the different market classes.**

For each market class the reported health problems affecting traded cattle are displayed on the x axis. The y axis indicates the percentage of markets where each specific disease was reported as one of the three main cattle health problems affecting the traded cattle.

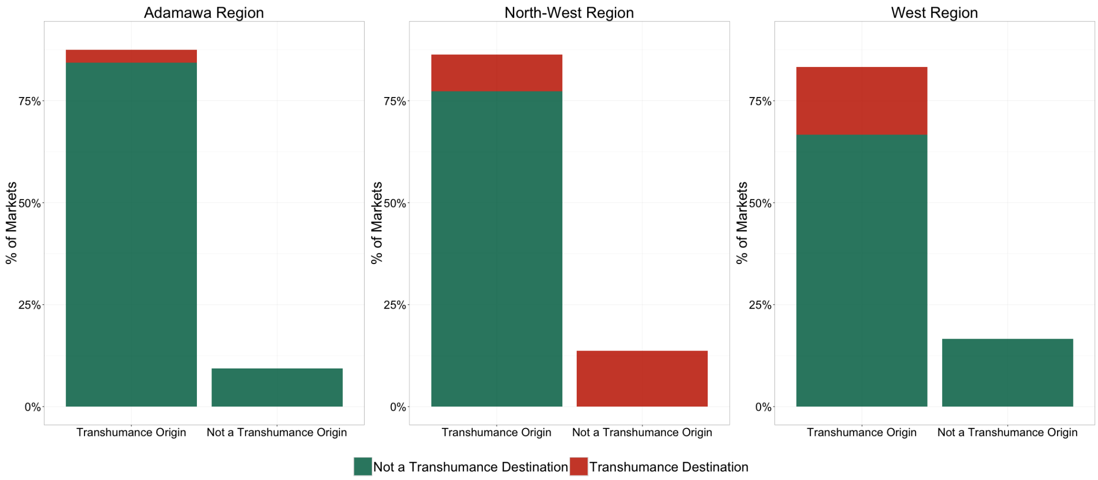

Figure 4.21: **Location of cattle markets in relation to transhumant zones within the three main study Regions.**
The x axis refers to markets located in zones known to be origins, or not, of cattle transhumance. On the y axis the green colour refers to the percentage of these markets which are not located in transhumant zones or, in other words, that are not transhumance destinations. The red colour, by contrary, indicates the percentage of markets that are located in transhumant zones, therefore, being destinations of herds coming from other areas.

both as transhumance origin and destination (Figure 4.18). These percentages were greater in the North-West and West Regions, respectively 9% and 18%. In the Adamawa and West Regions 8% and 18% of the markets, respectively, were located in areas which were not reported either as transhumance origins nor destinations. By the contrary, in the North-West Region the 16% of the markets were located in areas considered purely transhumance destinations but not as origins of transhumant herds.

Clearly, the three markets of Yaoundé, Douala and Kye-ossi were not included in this figure as they are located in urban or forest areas which are neither origins nor destinations of cattle transhumance.

4.3.8 Status and education level of the stakeholders (Q_2)

The vast majority of the interviewees were herdsmen (67%), followed by traders (19%), by respondents that reported being both herdsmen and traders (12%) and by butchers (2%) (Figure 4.19A). A total of 19% of the respondents in the Adamawa Region reported being formally educated, compared to 46% in the North-West and 40% in the West Regions (Figure 4.19B).

Across the Regions formal education was predominantly at primary level with a smaller proportion of interviewees reporting secondary level education, and tertiary education was, by contrast, reported only in the North-West Region (3%) (Figure 4.19).

These proportions were evenly distributed across the different classes of markets with about 25% of the interviewees reporting formal education in local, sub-regional and regional markets. In primary markets, by comparison, this percentage rose to about 70%, with around 40% indicating primary and 30% secondary education (Figure 4.19C).

4.3.9 Trading purposes of buyers and sellers (Q_2)

In the Adamawa and North-West Regions, the large majority of the interviewees who were selling cattle on the day of the survey reported that “buying household or farming inputs” was the driver to sell cattle (88% in the Adamawa and 85% in the North-West). However, this was the selling purpose of only 38% of interviewees selling cattle in the West Region (Figure 4.20A). Here, instead, the large majority of the interviewees reported that the motivation for selling cattle was to earn cash to buy a replacement animal from the market (Figure 4.20A). All the respondents interviewed at the markets of Yaoundé, Douala and Kye-ossi were

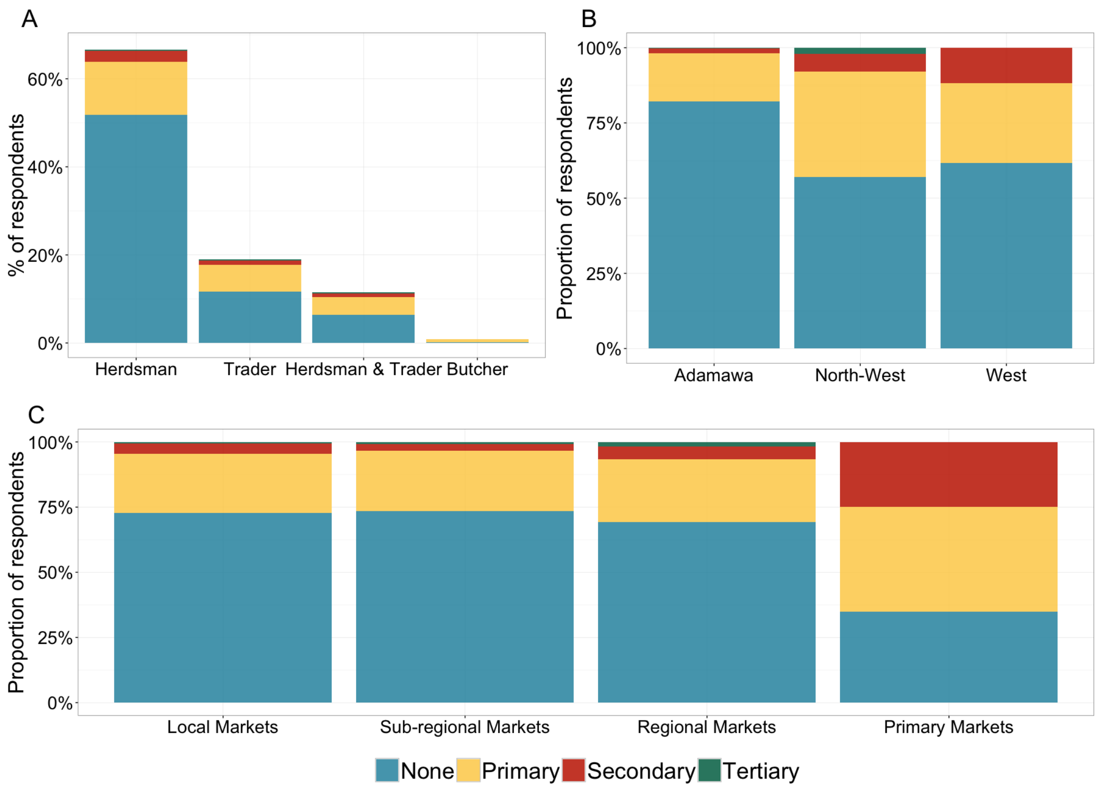

Figure 4.22: **Status of the stakeholders interviewed at the market level and their reported formal education (N=591).**
Figure A: Status of the participants at the survey and their formal education.
Figure B: Education level of participants across the three main Regions where the study was conducted.
Figure C: Education level of the participants across the four classes of markets identified with hierarchical clustering. The different colours refer to the education level of the respondents: any education (blue), primary education (yellow), secondary education (red) and tertiary education (green).

traders and did not provide any answer to this question.

When interviewees who were buying cattle on the day of the survey were asked to indicate the purpose of buying at the market, in the Adamawa and the North-West Regions, again, similar answers were obtained. The majority of respondents indicated that the purpose was to re-sell the animal in order to make a profit (45% in the Adamawa and 48% in the North-West), while about 25% in the Adamawa and about 30% in the North-West, respectively, indicated that the purpose for buying was breeding (Figure 4.20B). Similar proportions of interviewees in these two Regions (25% in the Adamawa and 30% in the North-West) reported that slaughtering the animal was the purpose for the purchase. A smaller percentage, by comparison, answered that cattle were bought as working animals (9% in the Adamawa Region and 2% in the North-West Region) (Figure 4.20B). In the West Region the large majority of cattle were bought to be slaughtered after purchase (80%), while 15% were for breeding purposes and 5% to re-sell and make a profit (Figure 4.20B). No buyers were interviewed at the markets of Yaoundé, Douala and Kye-ossi.

4.3.10 Unsold cattle at the market place (Q_2)

In the Adamawa Region the majority (68%) of the interviewees who were selling cattle on the day of the survey reported not having sold all of the cattle taken to the market (Figure 4.21A). In contrast, in the North-West and West Regions the minority of the respondents who were selling cattle reported not having sold all the cattle taken to the market, respectively 28% and 47%. When not all the presented cattle at the market were sold, the interquartile range of the number of escorting cattle was between 1 and 2 in the West Region, between 1 and 2.5 in the North-West Region and between 2 and 4 in the Adamawa Region (Figure

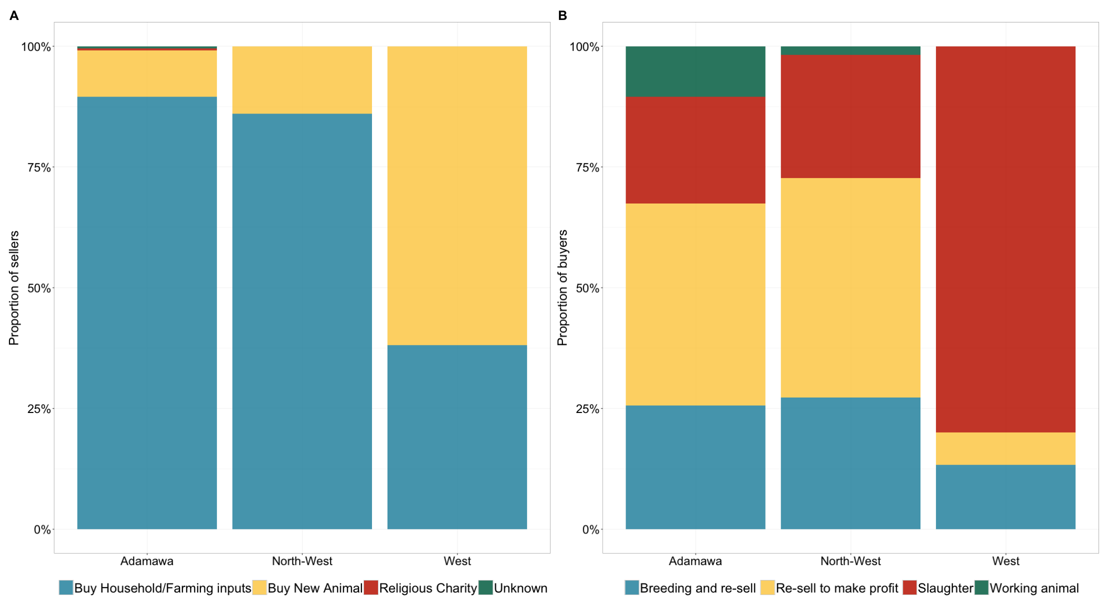

Figure 4.23: **Reported purposes for selling (A) or buying (B) cattle within the three main study Regions (N_{buyers}=162; $N_{sellers}$=396; $N_{buyers/sellers}$=12).**
Figure A: proportions of interviewees who reported selling cattle to buy households or farming inputs, to buy a new animal, for religious charity or for unknown reason. Figure B: proportions of interviewees who reported buying cattle; for breeding and then re-sell the animal; to re-sell shortly to make a profit; to send it to slaughter or to use it as a working animal.

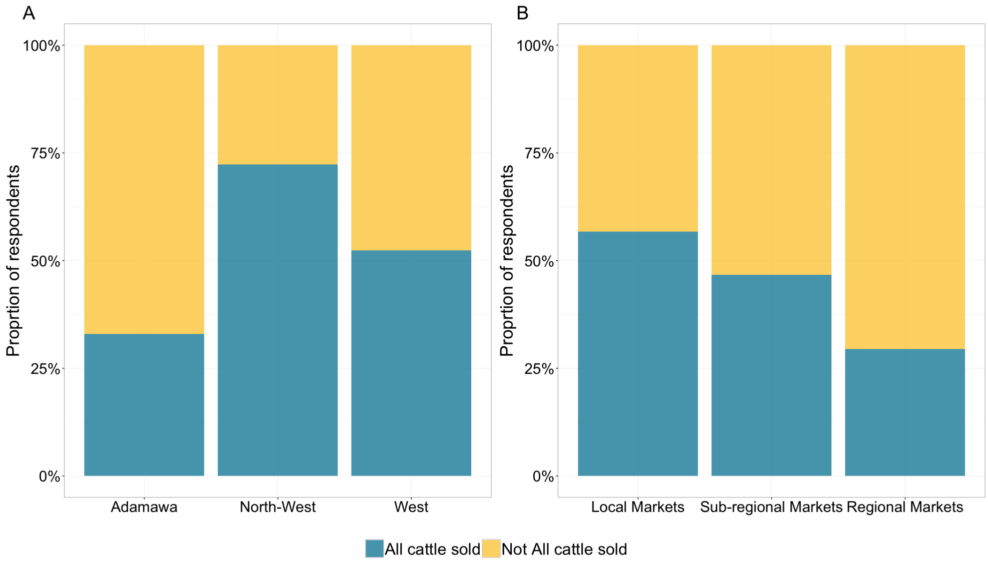

Figure 4.24: **Proportions of interviewee selling cattle and reporting having sold or not all the cattle brought to the market on the day of the survey (N=396).**
Interviewee who were selling cattle on the day of the survey were asked wether all the cattle brought to the market had been sold or not. The blue colour refers to the proportion of respondents indicating that all the cattle brought to the market had been sold. The yellow colour refers to the proportion of respondents indicating that not all the cattle brought to the market had been sold. Figure A: On the x axis respondents are grouped by Region; Figure B: On the x axis respondents are grouped by market class.
Note any unsold cattle were reported by the interviewees at the markets in Yaoundé, Douala and Kye-ossi.

4.22).

The three markets of Yaoundé, Douala and Kye-ossi were not included in this figure because all the respondents reported having sold all the presented cattle, as these are urban markets.

When comparing the different classes of markets 45% of the interviewees selling cattle at local markets indicated that they had not sold all the cattle brought to the market, while this percentage increased in sub-regional markets (53%) and in regional markets (70%) (Figure 4.21B).

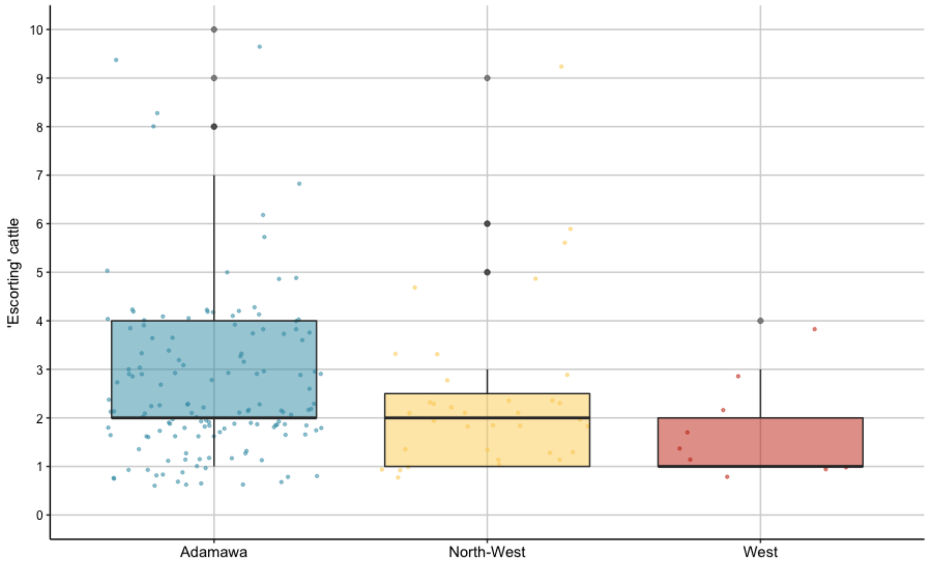

Figure 4.25: **Reported number of unsold cattle within the three main study Regions (N=197).**
Boxplot of the number of unsold cattle per seller who reported not having sold all the cattle brought at the market place on the day of the survey. For each box the dots refer to the number of unsold cattle, the upper and lower "hinges" correspond to the 1st and 3rd quartiles (the 25th and 75th percentiles) and the horizontal line to the median value.
Note any unsold cattle were reported by the interviewees at the markets in Yaoundé, Douala and Kye-ossi.

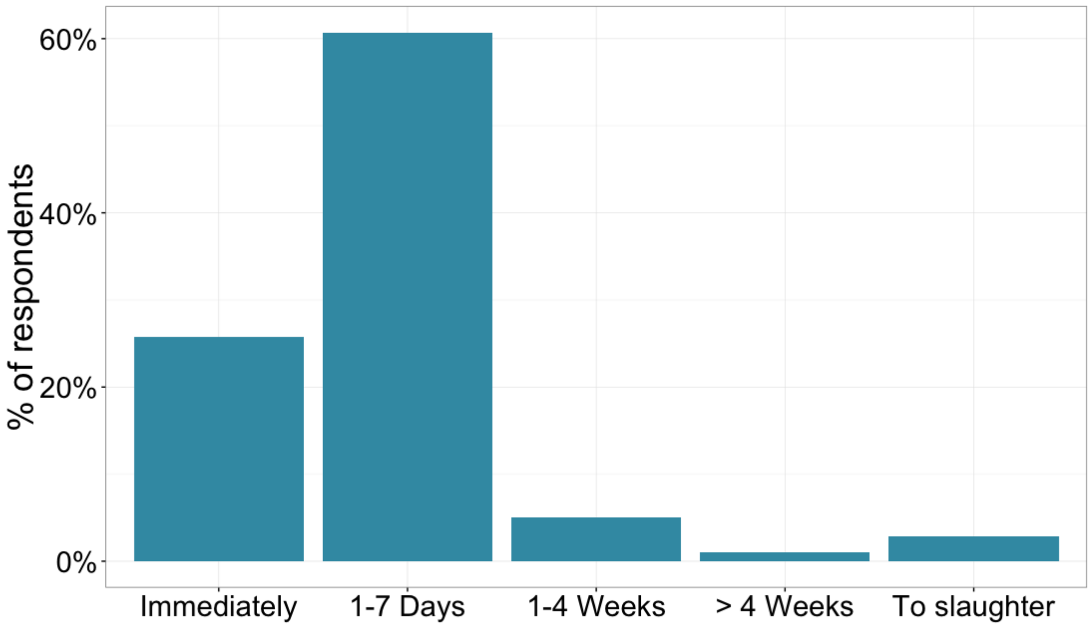

Figure 4.26: **Time of introduction in the herd of newly acquired cattle (N=591).**
The percentage of interviewees (on the y axis) who reported introducing in their herd newly acquired cattle from the market: on the same day, within a week, between 1-4 weeks, in more than 4 weeks or to send these animals directly to slaughter.

4.3.11 Acquisition and introduction of cattle in the herd (Q_2)

When asked about their practices in relation to the purchased cattle during the previous 12 months, 61% of the interviewees reported to have introduced these animals into their herds within a week from the date of purchase (Figure 4.23). Twenty-seven % of the respondents reported having introduced in the herd the purchased cattle on the same day as the purchase. Only 8% of the interviewees put in place some type of isolation before introducing the newly acquired animals in their herds: 6% kept the purchased cattle separated for a period ranging between 1 to 4 weeks, and 2% for more than 4 weeks. Only 4% of purchased animals were directly slaughtered on the same day of purchase.

4.3.12 Reported clinical FMD among acquired animals (Q_2)

When interviewees were asked if cattle purchased from the markets in the previous 12 months then subsequently developed clinical FMD, they provided overall consistent answers across the study area. Across the three main study Regions where the survey was carried out, between 20-30% of the purchased cattle during the previous 12 months were reported to have developed FMD after their acquisition from the market (25% in the Adamawa Region; 20% in the North-West Region; 30% in the West Region) (Figure 4.24A).

This proportion tended to increase between market classes from local toward primary markets. While about the 20% of interviewees at local markets reported that acquired cattle within the previous 12 months developed clinical FMD after purchase, these were 24% at sub-regional markets, 29% at regional markets and 62% at primary markets (Figure 4.24B).

4.3.13 Transhumant habits among the interviewees (Q_2)

Sixty-five percent of survey participants reported not undertaking transhumance during the dry season (Figure 4.25). Among the 35% of respondents who reported going on transhumance, their destinations were mainly within the same Division (19%), and to a minor extent to another Division of the same Region (7%), to another Region (9%) or to another country (less than 1%) (Figure 4.25).

Proportionally less respondents reported undertaking transhumance in the Adamawa Region (25%), compared to the North-West and West Regions (49% and the 46%, respectively). However, among interviewees in the North-West Region only 1% reported going on transhumance in another Region. In the West Region, by

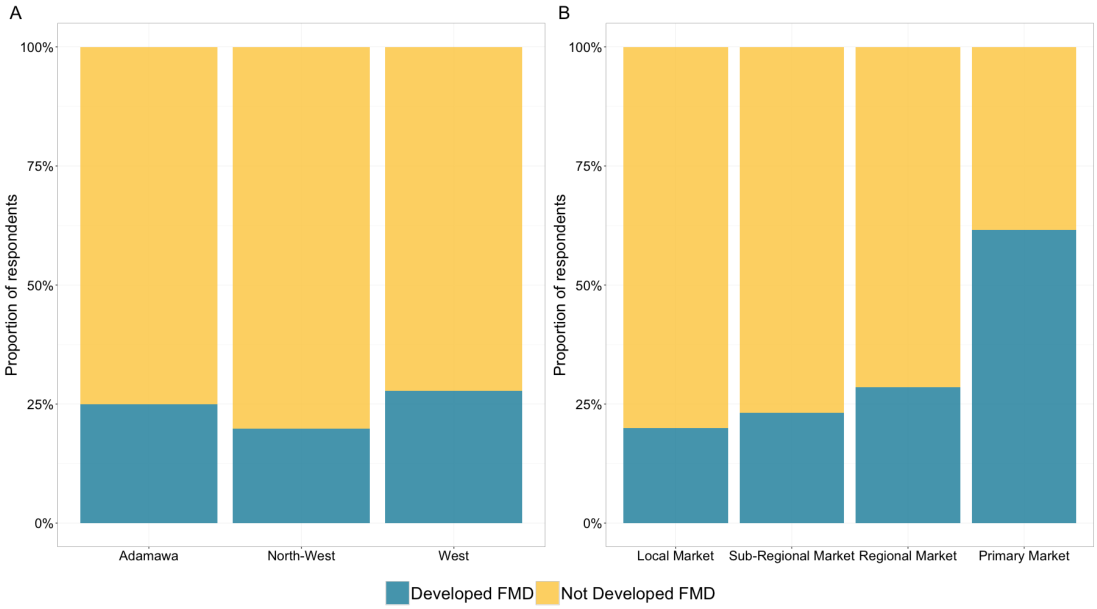

Figure 4.27: **Proportions of interviewee who reported clinical FMD cases among cattle acquired within the previous 12 months (N=566*).** The blue colour refers to the proportion of respondents who reported that cattle they have acquired from livestock markets within the previous 12 months developed FMD once they were introduced in the herd. The yellow colour refers to the proportion of respondents who reported that the acquired animals did not develop FMD. Figure A: On the x axis respondents are grouped by Region (3 main study Regions); Figure B: On the x axis respondents are grouped by market class.

Note1 in figure 4.24A the regional location of the primary markets is omitted and referred to in figure 4.24B.

Note2 twenty-five interviewees did not answer this question.

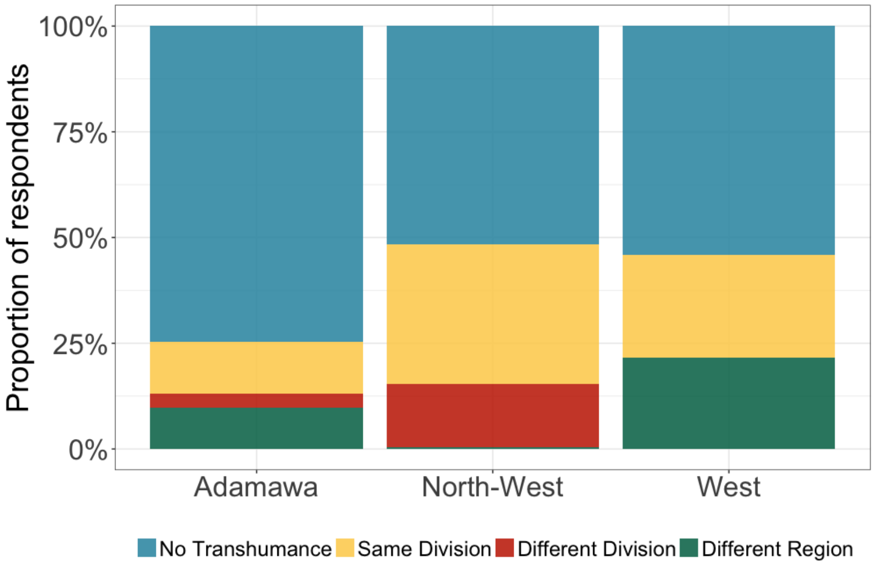

Figure 4.28: **Transhumant practices of the interviewee across the 3 main study Regions (N=570).**
Proportions of interviewees reporting either to take their herds on transhumance or not in the three main study Regions. Colours refer to the destinations of the transhumant herds: yellow within the same Division, red within the same Region but to another Division, green to another Region and black to another country.
Note any of the interviewees at the urban markets in Yaoundé, Douala and Kye-ossi reported taking their herds on transhumance.

comparison, about 50% of the interviewees reporting undertaking transhumance remained within the same Division while the other 50% went in another Region. In the Adamawa Region the patterns were more heterogeneous with about 50% of the interviewees reporting keeping their herds within the same Division during transhumance, 10% going to another Division of the Adamawa and the 40% going to another Region.

4.4 Discussion

Cattle trade in Cameroon mainly occurs via multiple intermediate steps in the form of conventional marketing infrastructures generally constructed and owned either by the Government or by the Municipalities. Cattle are traded all year around and livestock markets are held on a weekly basis. Markets are key gathering points for the livestock sector where various stakeholders carry out central activities for the trading of cattle as well as for social networking and, often, for buying farming and household inputs. Live animals markets are known to be major contact points in livestock populations which not only facilitate trade and social interactions but also play critical roles in the dispersal of infectious diseases in diverse farming systems and in various regions of the world (Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Rautureau et al. [2011]; Dean et al. [2013]; Fournié and Pfeiffer [2013]; Vallée et al. [2013]; Molia et al. [2016]).

Acquiring new knowledge and increasing the understanding of the characteristics of the cattle trading system, the livestock markets and the common practices of the stakeholders involved in this sector, is key to improving the management of animal health and of the circulation of diseases. As learned from the 2001 FMD epidemic in the UK, when the lack of a clear understanding of the structure of the sheep industry and trade was one of the factors contributing to the size and extent of the epidemic, this knowledge is key both for emergency preparedness and for ongoing surveillance programmes (Scudamore [2002]; Haydon et al. [2004]).

Based on primary data collected during this project, the overall purpose of this chapter was to characterise the cattle marketing system in the study area, describing the volumes and features of the traded animals, as well as the main characteristics of the cattle markets and provide an overview of the practices of the stakeholders involved in this system.

In this chapter, four classes of cattle markets were identified as representative of different types of trading points within the study area. Local markets can be considered as collection markets, generally small trading points located in the grazing zones where animals are traded between local herders and a relatively small number of traders from the surrounding areas. Sub-regional markets generally are medium-size trading points also located in grazing zones where local herders and butchers come together with traders to trade cattle originating from both the surrounding villages and from local markets within the neighbouring administrative districts. Regional markets are generally located in, or close to, regional administrative or commercial hubs or in strategic towns along the tar roads or the railway. These markets usually act both as terminal markets, where cattle enter the food chain for human consumption, and as final collection markets where animals are gathered and directed towards the big national primary markets. Primary markets are terminal trading points located either in the biggest urban centres of the country or in proximity of national borders where transactions are carried out between traders, butchers and exporters while herders are generally not present at these markets.

The trends of cattle volumes and of their commercial values varied over the year and across the Regions included in this study. These regional differences were accompanied by diversities in the proportions of the type of traded cattle. As expected by its larger cattle population, the volume of traded cattle in the Adamawa Region was the largest of the entire study area. Nevertheless, major primary markets in Douala and Yaoundé each traded almost as large volumes of cattle over the year, as the Adamawa Region. This suggests that, even though the Adamawa is the main cattle provider for the trading system of the country, alone it cannot sufficiently satisfy the live animal demand of the major urban centres of the country. Consequently, it is likely that these high demand primary markets receive cattle from multiple areas and regions of the country, such as the West and North-West as well as the North and Extreme North Regions.

The market supply of live cattle showed similar trends over the year and across the Regions. Although overall the peak of cattle in the market system was in December 2013, the trade volume was consistently larger during the months of the rainy season and a decrease was recorded during the dry season (October to April). In December, celebrations for the end of the year and, in Regions with a Christian majority, religious festivities are likely to trigger an increase in demand for meat products, and therefore, for live animals. Religious events have already been seen to trigger an increase in livestock movements in order to satisfy a growth in the demand of animal and animal products in other settings (Knight-Jones et al. [2016]), suggesting that this could be a plausible driver of cattle trading also in the Cameroonian contexts. This hypothesis seems to be supported by the fact that, across the study area, the proportion of adult cattle traded on the market (bulls, cows and steers), and therefore, suitable for human consumption, consistently increased towards the end of the year peaking in December. The present study also showed that market stakeholders, depending on the class of markets within the trading system, reported diverse motivations as their main driver for trading cattle. In particular, interviewees attending primary markets, mainly reported cattle purchases were for slaughter, supporting the assumtpion of human consumption of animal products as a key driver for trade in this market class.

The scarcity of grazing areas and of available water sources during the dry season, while triggering transhumance for many herds towards better pastures, may also directly affect the health status of the herds, reducing the trading appeal and value of the cattle (Lamy et al. [2012]). Conversely, increased pastures and water availability during the rainy season provide the opportunity for the herds to rapidly recover from the hardships of the dry season also re-gaining weight, improving their general health status and, eventually, their suitability for trade triggering an increase in the volume of cattle trade. A similar increase of the cattle trade volume during the rainy season is not unusual in SSA and has been observed also in the Amhara Region across the Ethio-Sudan border where cattle supply increases during the rainy season (Mulugeta et al. [2007]). In the present study we also observed that about 35% of the interviewees reported that their herds usually undertook transhumance. Given this finding it is likely that the actual cattle population in the vicinity of the markets is reduced during the dry season, suggesting a plausible explanation for the drop in cattle trade volume during the dry season. This was particularly the case in the Adamawa Region where among the interviewees reporting to drive their herds on transhumance, 50% indicated that their destinations were in another Division or in another Region.

However, it is worth noting that during the present study the Islamic Ramadan fasting month occurred in July 2014. In the Adamawa, a predominantly Muslim Region, this might have possibly affected cattle trade. Selling livestock is considered a major source for rapid cash generation for the rural population (Delgado et al. [2001]; Thornton [2002]) and, in fact, in the Adamawa Region the vast majority of the respondents reported selling cattle for procuring households and farming inputs. It is reasonable to think that households, in preparation for the celebrations for the end of the Ramadam, increased the cattle supply on the market as a mean for rapid generation of income for this specific celebration.

The reduction in the volume of cattle available at the market during the dry season was accompanied, conversely, by a relative increase of the cattle price. Overall cattle tended to be slightly more expensive during the dry season compared to the rainy period. This pattern was more evident in the primary markets located in the high demand urban centres of Yaoundé and Douala, and only observed to a minor extent in the cattle production areas of the North-West and Adamawa Regions. A possible and intuitive explanation for the relatively higher price during the dry season could relate to the lower supply of healthy and fattened cattle particularly suitable for human consumption and, therefore, generally traded above all in markets located in high consumption urban centres.

Overall, a cattle price differential was highlighted between production regions and high consumption areas. This was evident for adult animals (bulls, cows and steers), which also represented more than 90% of the cattle traded in the high consumption areas. Across the study Regions, adult animal predominated in the markets in the North-West Region representing more than 80% of the traded cattle and in the West Region, where they accounted for almost the 75% of the trade volume. On the contrary in the Adamawa Region we observed an equilibrated trade structure of cattle types, with a 1:1 ratio between young animals, below 3 years (heifers and young bulls), and adult animals.

While adult cattle are more likely to be traded for consumption purposes, in pastoral systems where the life span of cattle not destined for human consumption is usually 10 years of age or more (Njoya et al. [1999]), adult animals may also be traded for breeding and reproductive purposes. In the Adamawa and in the North-West Regions, in particular, around the 25% of the participants in the survey reported acquiring cattle on the market for breeding purposes (while in the West Region this percentage was halved). Young and adult animals might have different biological and epidemiological implications with regard to the spread of infectious diseases within the cattle trading system. In Cameroon multiple diseases are considered endemic and individual animals during their lifetime can become infected with multiple pathogens as well as potentially be simultaneously infected with different pathogens. For instance, in the case of rapidly spreading infections, such as FMD, young animals are usually more susceptible to develop relatively easily detectable clinical signs and, also, more prone to pathogen dissemination (Grubman and Baxt [2004]). In general, as cattle bought for breeding purposes are, by definition, then introduced permanently in new areas and within new herds, the clinical assessment at the market level for these animals is of even greater importance and ideally should account for these biological and epidemiological age differences.

In the Adamawa and North-West Regions, as in regional and primary markets across the whole study area, FMD was reported as the most common disease affecting traded cattle, followed by dermathophilosis and trypanosomiasis. Conversely, in the West Region, as well as in local and sub-regional market classes, dermathophilosis was the most commonly reported cattle health problem, followed by FMD and trypanosomiasis. Other infectious diseases and health conditions affecting traded cattle often reported included piroplasmosis, CBPP as well as endo- and ecto-parassites.

Along with dermathophilosis, bovine tubercolosis (bTB) was reported as another potential zoonotic infection affecting traded cattle. While reporting of bTB cannot be other than a suspicion, given the diagnostic challenges of this context, it highlights that zoonotic diseases are circulating within the cattle trading system. This supports recent findings of high prevalences of *Mycocterium bovis* in slaughtered cattle in abattoirs in central and northern Cameroon (Egbe et al. [2016]). In Cameroon, other major zoonotic diseases that are known to be present within the cattle population include brucellosis, leptospirosis, Q fever and RVF (Zaria [1993]; Scolamacchia et al. [2010]; Kelly et al. [2016]). Unfortunately, given the time constrains for the administration of the questionnaire with the market stakeholders we could not include investigations of the behaviours at risk for human infections with these zoonotic pathogens.

An obvious limitation of this study is that the reporting of these diseases were only anecdotal and obtained through oral interviews without any supporting laboratory evidence. Furthermore, clinical symptomatology in some cases might not clearly indicate the causal agent and differential diagnosis should be considered if multiple diseases might cause similar symptomatology. Nevertheless, the most commonly reported diseases in study (FMD, dermathophilosis and trypanosomiasis) tend to present characteristic and peculiar symptomatology and herders across the study area are known to be aware of and to be able to recognise key livestock disease, such as FMD (Morgan et al. [2014]). In addition, due to their high prevalence within the cattle population, knowledge of these diseases is also common among other market stakeholders (Kelly et al. [2016]).

In central Cameroon FMDV serotypes O, A and SAT2 have been circulating since at least the 1990s (Bronsvoort et al. [2004a]) while also SAT1 and SAT3 have been recently identified in the Far North Region of Cameroon (Pomeroy et al. [2015]). In particular, about 60% of the cattle herds in the Adamawa Region are estimated to be positive for FMDV infection (Bronsvoort et al. [2004a]). In the current study, across the 3 main study Regions, between 20% and 30% of the participants reported that cattle acquired from the market system within the previous 12 months then developed clinical FMD. This percentage was lower in local markets and tended to progressively increase in sub-regional, regional and primary markets, respectively. These results support previous findings suggesting cattle trade as the main route of entry and dissemination of FMDV in Cameroon (FAO [2015]). However, it is important to note that the results regarding primary markets are likely to be biased by the smaller sample size and by the fact that interviewees in these markets were all traders. In primary markets, traders traded more cattle over the year compared to stakeholders in other market classes having, therefore, more chances to identify clinical signs of FMD in purchased cattle. It is also possible that the incentive to avoid clinically diseased cattle is lower for traders, compared to herders, as they are not going to introduce the purchased animals into their herds and, instead, could potentially exploit this clinical condition to lower the prices during negotiations.

Bovine dermatophilosis is a common disease in the tropics estimated to affect about 90% of the herds in the central African region (Awa and Achukwi [2010]). In Cameroon is a leading cause of production loss, being specifically indicated as the third most important cause of milk loss in dairy cattle (Awa and Achukwi [2010]). As with FMD, dermatophilosis is considered a highly contagious disease, for which management practices could have major impacts for its dissemination. In the present study more than 85% of the interviewees reported introducing newly purchased animals into their herds in less than a week from purchase. Clearly this practice facilitates the spread of pathogens and should represent an important aspect to be considered in designing communication and awareness interventions, such as the adoption of isolation periods before the introduction of purchased animals into their herd.

Another interesting finding was that not all the cattle that are present at the market are eventually sold and, hence, if owned by herdsmen are then reintroduced in their herds of origin. In the Adamawa, West and North-West Regions, respectively, about the 70%, 50% and 30% of the participant in the survey reported not having sold all the animals that were presented at the market on the day of their interview. While this could be due to failed negotiations or a lower demand than expected on the market on the day of the survey, it is important to note that a common practice among herdsmen is to walk to the markets with some additional cattle other than the ones for sale. The reasoning behind this "escorting" practice is because animals are more easily handled during the trek to and from the market if they are accompanied by some adults from the herd. Newly purchased animals, as well, are more docile if accompanied by other cattle on the way to their new herds. Obviously, this practice poses additional risks both for the spread of infectious diseases at the market level and for the introduction in the herd. However, this specific practice is understandably adopted to overcome a practical management problem, particularly during long treks to markets. It is likely such a habit is not easily modifiable in a short period and efforts should rather focus towards mitigating the potential risks of this practice. "Escorting" cattle could be left outside the sale pens, ideally completely denying their access to the trading area, and when brought back to the herds should observe isolation periods before re-introduction in the herd, together with the newly purchased animals.

Another relevant factor for the dispersal of infectious diseases is represented by the encounter between different livestock species at the markets. Across the study area, although swines have never been found to be traded within this circuit (most likely because the cattle trading system is largely managed by Muslims) small ruminants and birds were often present at the trading points. Even tough rarely these livestock were sold together with cattle within the same sales pen, their presence could be relevant for the epidemiology of specific infectious diseases such as FMD, for which small ruminant tend to present more subtle clinical manifestation, therefore, representing an additional risk for infection dissemination.

Bovine trypanosomiasis is another leading cause of production loss. Indigenous *Bos taurus* cattle, which have developed tolerance to trypanosomiasis, represent only 1% of the Cameroonian cattle population (Pamo [2008]). *Bos indicus* and recently imported *Bos taurus*, which together represent almost the entirety of the Cameroonian cattle population (Pamo [2008]), require a careful management and treatment with trypanocides. In Cameroon trypanosomiasis is particularly prevalent in areas where rainfall is above 1000 mm per year, where also vector density is higher (Awa and Achukwi [2010]). These areas offer greener pastures and greater water availability and, often, are also destinations for transhumant herds. In this study we couldn't investigate the actual destination of transhumant herds, however differences across Regions were highlighted with regards to the transhumance habits of the cattle owners. In the Adamawa and West Regions about 50% of the herds undertaking transhumance reported migrating outside their Region of origin, while almost the totality of the transhumant herds from the North-West Region remained within the regional boundaries. Participants in the study from the Adamawa and West Regions often reported trypanosomiasis as one of the main diseases affecting cattle herds compared to the North-West where this disease was cited with a lower frequency. The different migratory habits and the higher variability of landscapes encountered during these migrations might represent a possible explanation for these differences of reporting across the Regions.

In the North-West Region around 20% of the markets were located within areas considered to be transhumance destinations, while this was never the case in the Adamawa and West Regions. The combination of a vastly predominant internal transhumant movements and of an overlap between market locations and transhumance destinations might suggest that in the North-West Region cattle herds tend to have a much closer contact structure providing higher chances for interaction compared to the other two Regions included in this study.

One of the main shortcomings of this study was the use of a convenient sample for interviews. However, the very dynamic nature and diversity of the the livestock markets prohibited any more statistically robust approach to the sample design and, therefore, caution must be used in the interpretation of these results. In addition, despite our efforts in the design of the study and in carrying out the interviews, the use of a questionnaire-based survey might have introduced different types of bias within the study, including bias caused by the different languages the questionnaires have been translated into (Choi and Pak [2005]).

Nevertheless, we can be confident that the experience of the principal interviewer and his reputation within the livestock sector have helped reducing some of these shortcomings. We are clearly not assuming that this is a complete representation of the marketing system in Cameroon, particularly because we could not complete the study in the North and Extreme-North of the country. However, we can be confident that this study provides the first characterisation of the trading system with a focus on both basic socio-economic aspects and animal health features, hopefully acting as a baseline guide for future studies and for the implementation of awareness and training campaigns addressed to the market stakeholders.

4.5 Conclusion

In conclusion this study highlighted:

1. The presence of 4 classes of cattle markets: local collection points, sub-regional and medium size trading points, regional markets relevant for both national and international trade as well as for human consumption, and primary markets mainly for human consumption or export of cattle.

2. Regional differences in the trade volumes and cattle prices:

    - despite peaking in December, across the study area the cattle supply was consistently higher during the rainy season (May-September) and accompanied by a relatively lower mean price per head of cattle compared to the dry season;

    - the Adamawa was the Region with the highest number of traded cattle, of which the 50% were young animals below three year of age, while this proportion was respectively 25% and 20% in the West and North-West Regions;

    - a high price differential was observed between the three livestock production Regions and the primary markets in the southern Regions of the country;

3. Key animal health and management practices within the cattle trading system:

    - FMD, dermatophilosis and trypanosomiasis were consistently reported as the most commonly observed diseases affecting traded cattle;

    - a relevant proportion of market stakeholders tend to bring more cattle at the market than the ones actually on sale and the vast majority reported introducing the acquired cattle into their herds within few days of purchase;

- other livestock are often present at the trading point, particularly in the Adamawa Region.

4. Cattle transhumance habits differed across the study Regions:

    - overall the seasonal migration was undertaken by more than a third of the market stakeholders across the study area, possibly contributing to the drop in cattle supply to the markets during the dry season;

    - cattle markets and transhumance locations showed to overlap in some areas under study: particularly the North-West Region seems to present a closer interaction between the trading pathways and the transhumance patterns.

5. Key point for surveillance, awareness and training campaigns:

    - herders and traders reported different trading purposes which may reflect different perspectives of managing animal health and which need to be accounted for when addressing these different stakeholders;

    - to improve the management practices at the trading points priorities should be the reduction of mixing between different livestock species, the separation of animals on sale and the one which are not taken to the market for trading purposes, the increase of qualified personnel to carry out clinical inspection of cattle presented and the improvement of the infrastructure in order to implement hygiene and biosecurity measures;

    - to improve herd management practices at the herd level information on disease transmission and control should mainly focus on the diseases reported as major problems across the cattle trading system; nevertheless, awareness campaigns should aim at creating a general horizontal impact improving the awareness of "good standard operational procedures" with impact on multiple diseases. Risk management strategies should highlight the importance of separation between the herds and the newly purchased/escorting animals, as well as principles of preventive management practices for better coping with environmental conditions during the dry season, such as hay stocking or crop residues feed supplementation as an example;

- to improve disease reporting and surveillance sensitivity market stakeholders should be involved in a "passive" reporting scheme which would, simultaneously, empower them as central actors for the management of animal health and increase the cost-effectiveness of awareness and training campaigns;
- these interventions should consider the seasonal variations of cattle trade in order to maximise the outreaching as well as the efficiency of potential informal disease reporting systems.

Chapter 5

Characterisation and modeling of the cattle trading network

5.1 Introduction

Movements within and between populations are a central driver of disease dynamics defining the patterns of interactions and the susceptibility to the spread of a wide range of infectious agents (Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Dubé et al. [2010]; Smith et al. [2013]). Livestock trade is of particular importance, since pathogens can be transmitted over long distances via movement of infectious animals. Understanding the structure of livestock contacts and studying the routes, volumes, frequency and the risks associated with animal movement represents a prerequisite for effective animal and zoonotic disease surveillance and control.

Most industrialised countries have implemented animal identification, registration and tracing systems to enhance strategic and targeted approaches for disease surveillance, to develop early warning systems for outbreak detection and for more informed control measures (OIE [2014]). However, in most lower income countries there is still limited information on livestock movements with no systematic recording systems (Todaro and Smith [2014]). Despite variations in the level of organisation across countries, livestock trade often occurs via local, regional or national livestock trading points and commodity markets. These markets represent major contact points in livestock populations which not only facilitate trade and social interactions but also play critical roles in the dispersal of infectious diseases in diverse farming systems (Keeling and Eames [2005]; Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Rautureau et al. [2011]; Dean et al. [2013]; Vallée et al. [2013]).

In Cameroon, the livestock sector is rapidly evolving toward a more market-orientated system and represents an important source of revenue for about 30% of the rural population (Pamo [2008]). While organised around traditional smallholders, the Cameroonian livestock industry depends on a well established and structured livestock market system to facilitate trade. Therefore the flow of animals within the country can be described as a network which considers markets as nodes that are linked by the transfer or movement of animals.

In general, the structural characteristics of such networks are known to influence the potential dissemination of infectious agents (Barabási and Albert [1999]; Christley et al. [2005]; James et al. [2009]). For example, networks in which most connections (or links) in the network are held by a small number of nodes are known to ease the spread of infectious diseases (Barabási and Albert [1999]; Barabási and Bonabeau [2003]). Of particular interest are the so-called small-world networks, characterised by the tendency of neighbouring nodes to cluster together and, simultaneously, by the presence of few long distance connections linking local clusters standing far apart within the network (Shirley and Rushton

[2005]; Dubé et al. [2011]). This high clustering can facilitate the rapid local spread of socially transmitted diseases (James et al. [2009]), whereas the long ties can result in the dissemination of pathogens to distant areas of the network (Keeling and Eames [2005]; Dubé et al. [2011]). The number and size of subgroups of nodes, or components, which compose these networks would therefore affect the cohesion of the overall structure and, consequently, the potential impact of infections over the network. Knowing the size and location of these components is not only critical to assess the potential of the network to generate large epidemics (Kao et al. [2006]; Kenah and Robins [2007]; Volkova et al. [2010]), but also provides a basis to identify nodes which are key for the cohesion of the network. In an epidemiological context, this information is critical (Edwards et al. [2004]; Kiss et al. [2006]; Natale et al. [2009]), particularly by facilitating the design of targeted communication, monitoring, surveillance and control programmes and increasing the cost-effectiveness of interventions.

In this chapter we carried out the first formal study of the livestock trade network in Cameroon using a social network analysis approach. Combining the collection of official trading data and a questionnaire based survey at livestock trading points throughout Western and Central-Northern Cameroon carried out between October 2014 and May 2015, we present the analysis of the annual cattle movements through livestock markets at a national level.

5.1.1 Objective

The major objectives of this chapter were to (1) characterise the current formal cattle movements through the network formed by the livestock trading system, (2) to quantify the flow of cattle within this network and (3) to identify key markets for the design and implementation of surveillance, control and communication interventions.

5.2 Materials and Methods

5.2.1 Market identification

For the study area a list of the livestock markets was obtained from the relevant Regional Delegation of the MINEPIA and it was evaluated in consultation with local livestock experts. The approach to identify the livestock markets is described in detail in Section 3.2.2 and enabled to identify a total of 62 cattle markets within six Regions where active data collection was carried out (Table 3.1 and Figure 3.2). Information relative to the commercial connections during the previous 12 months was gathered from all markets identified through this approach and allowed to identify a total of 127 markets located in Cameroon and five neighbouring countries (Figure 5.1)

5.2.2 Data collection (*R_1, R_2 and Q_1*)

From October 2014 to May 2015 official transaction market records (R_2) were collected in all livestock identified markets. Together with this documentation, official reports were also collected from the relevant offices of the MINEPIA (R_1). Data for a 12 month period from September 2013 to August 2014 was extracted from this official documentation (see Sections 3.3.1).

Although the number of animals traded during each market day was consistently reported, the origins and destinations were not recorded consistently between Regions. To confirm the data obtained from these sources and gather

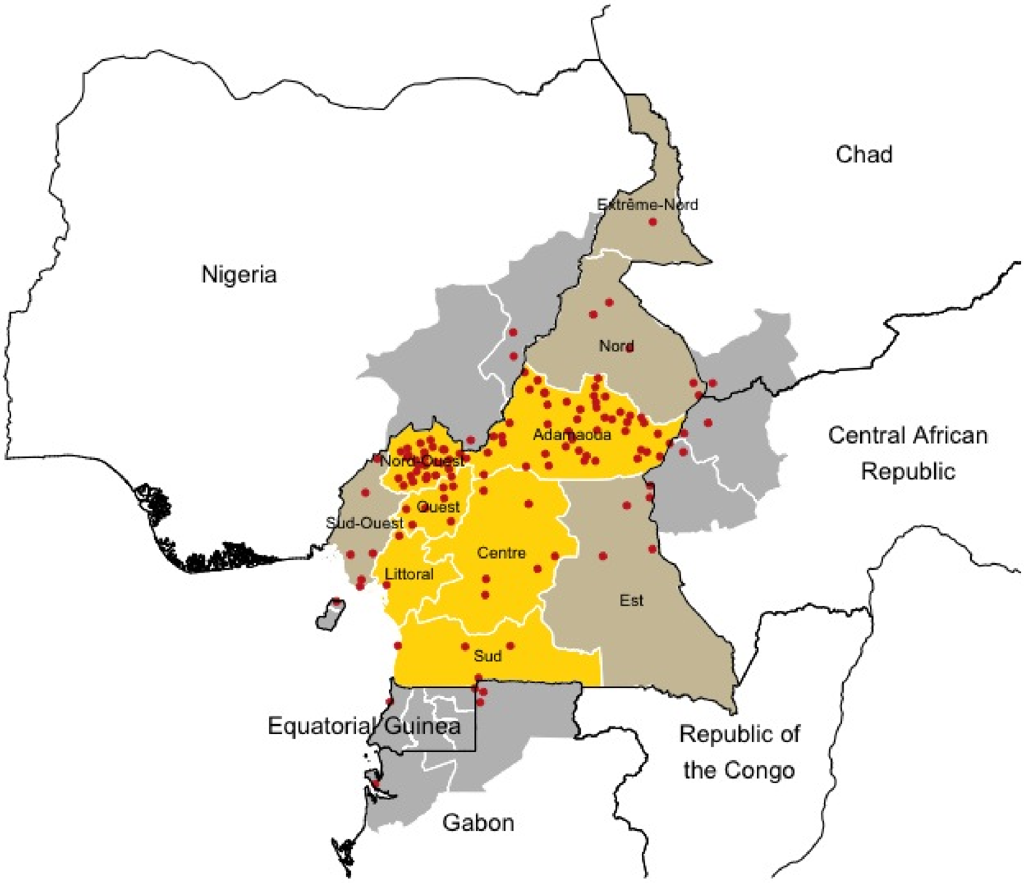

Figure 5.1: **Study area and locations of the livestock markets included in the analysis.**
The Regions in yellow highlight the areas where data collection was carried out. Regions in gold are the areas of Cameroon that were not visited during the study but for which were identified trading links with livestock markets localised in the sampling areas. In grey are highlighted Regions of neighbouring countries where livestock markets outside Cameroon are connected with the trade network

information where missing, semi-structured interviews were conducted with the veterinary officials and market managers (Q_1) (see Sections 3.3.2).

The proportion of the data that was provided by official reports and the proportion obtained by the interviews with the veterinary officials are shown in Figure 5.2. Sixty-six percent of these reports were complete, including data on the number of traded animals, their origins and destinations for the whole 12 month period (Figure 5.2B). With regards to the origins and destinations of the traded cattle, among this 66% of reports with complete data the 92% were also consistent with the information gathered through the interviews with the veterinary officials (Figure 5.2C). When the documents were complete information was prioritised from this source while when this data source was not complete the missing information was obtained from the interviews. In the restricted proportion of cases for which both official documentation and survey data were available and not matching (8% of the cases in which complete documentation was available) the official source was prioritised compared to the results of the interview.

5.2.3 Markets network construction

Data regarding numbers, origins and destinations of cattle movements only between markets were extracted from the database created combining the information from the data sources (R_1, R_2 and Q_1) and then used to build a weighted static directed network. Movements between markets and villages were excluded from the network building for two reasons. Firstly, because the objective of the analysis was to focus only on the markets trading network and, secondly, because it was often not possible to clearly identify the names of the villages. Frequently, villages have very similar names also within very close areas, consequently making it very complex to distinguish these locations and physically locate these villages

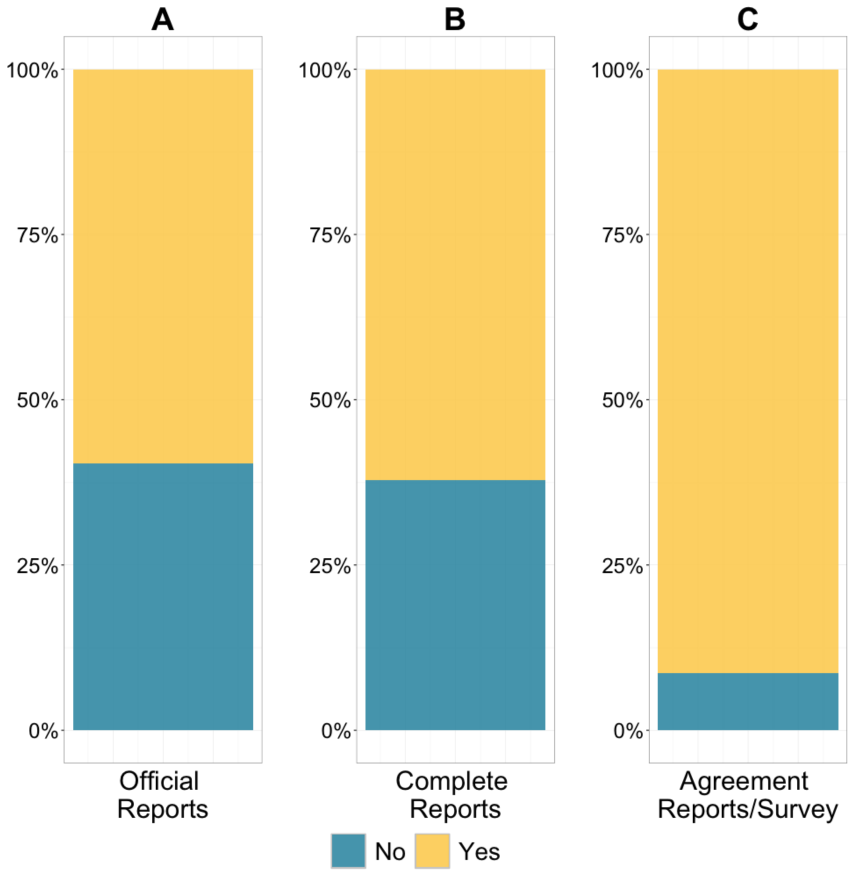

Figure 5.2: **Proportions of data on destinations and origins that were provided by the different data sources.**
Panel A shows the proportion of information on origins and destination of cattle that was obtained from the official reports compared to the proportion from the interviews with the veterinary officials (Yes = from official reports; No = not from official reports). About 60% of these information could be obtained from the official reports and of this, 66% of these were complete records while 34% of the reports were incomplete (Panel B). Among the complete documents 92% of the reported information were consistent with the one obtained from the interviews (Panel C).

also for local experts.

Markets formed the nodes of the network and the links between markets were defined as the movement of at least one animal from an origin market to a destination market. These contacts were described according to the direction of the movement and weighted by the number of cattle that were traded over this link. Data were aggregated over a 12 month period and stratified by the two seasonal intervals, October to April for the dry season and May to September for the rainy season. All network measures and summary statistics were estimated on the annual and seasonal networks to assess seasonal variations in both network centrality and connectivity metrics.

5.2.4 Network analysis

Description of the cattle trade network in Cameroon was carried in two steps: (1) we looked at the topology of the network, particularly by assessing if the cattle trade network has a small-world structure; and (2) by identifying key markets solely based on their node centrality measures. All network and node centrality measures used in this analysis are defined in Table 5.1.

Table 5.1: Network-level and node-level metrics.

Measures	Definition
Network-level metrics	
Density	Number of edges in the observed network relative to the total number of possible edges in a completely connected network

Table 5.1: Network-level and node-level metrics.

Measures	**Definition**
Reciprocity	Proportion of edges showing mutual connections (measure of the tendency of vertex pairs to form mutual connections between each other)
Degree Assortativity	Quantifies the tendency of individual nodes to connect with other nodes which are similar to themselves in terms of degree centrality
Average path length	Average number of edges that must the traversed to connect any two nodes in the network, without accounting for the temporal dimension of the connections
Diameter	The shortest distance/path length between the two most distant connected nodes in the network (= the longest of all the calculated path lengths)
Clustering coefficient (CC)	Proportion of pairs of neighbors of a given node which are connected, measures the tendency of the network to cluster
Giant strongly connected components (GSCC)	The largest subset of nodes that are mutually reachable through directed paths
Giant strongly connected components (GWCC)	The largest subset of nodes that are mutually reachable through undirected paths, therefore not accounting for the directionality of connections
Node-level metrics	
In-degree	Computed accounting for both the number of connections that each node receives in a defined period and the weights of these connections, hence a measure of the potential sources or origins of infection in that range of time
Out-degree	Computed accounting for both the number of connections that each node sends in a defined period and the weights of these connections, and therefore the number of potential destinations of infection in that range of time

Table 5.1: Network-level and node-level metrics.

Measures	**Definition**
Betweenness centrality	Frequency with which a node is located on the shortest path length between any pairs of nodes, accounting that the connection between nodes might be stronger along paths with more intermediate nodes that are strongly connected than paths with fewer weakly-connected links. In other words it is a measure of the tendency of connecting nodes which would be otherwise disconnected
Eigenvector centrality	Indirect measure of centrality determined by the centrality scores of the nodes to which the node of interest is connected
Key actors	
Gate-keepers	Central nodes in terms of their ability to bridge between the functional basis of the network and the wider community of nodes. They are characterised by high betweenness centrality and low eigenvector centrality values
Pulse-takers	Represent the functional basis of the network, are nodes with the shortest paths therefore easy access to other central nodes as well as to the rest of the network. They are characterised by high eigenvector centrality and low betweenness centrality values
Dual functionality	Nodes that fulfil the same bridging role as gate-keepers simultaneously having easy access to all areas of the network. They are characterised by both high eigenvector centrality and betweenness centrality values

Network topology

Topology of the observed cattle trade network in Cameroon was first described by using various network-level metrics, including *density*, *reciprocity*, *degree assortativity*, *average path length* (PL) and *clustering coefficient* (CC). A network is said to have a small-world structure if its CC is significantly higher than that computed from a random network of equivalent size and connections (that is with same number of nodes and links), while showing a lower value of PL (Wang et al. [2012]). We, therefore, assessed if the observed empirical cattle trade network has a small-world structure by comparing its CC and PL measures with those computed from a set of 1000 randomly-generated networks.

Node-level metrics were further computed to evaluate the centrality of each individual market within the network. These measures included *in-* and *out-degree*, *betweenness* and *eigenvector* centrality (Table 5.1). These centrality metrics were computed over the weighted directed network, accounting for the weights of the connections (Opsahl et al. [2010]).

Nodes characteristics and key-actors analysis

Identification of key markets was investigated through a correlation analysis between nodes centrality measures. Markets were classified depending on their relationship between *eigenvector* centrality and *betweenness* centrality. This analytic approach was derived from the study of the relationships among network metrics by Valente et al. [2008] and was previously applied to identify central actors of covert social networks by Conway [2010]. The residuals of the linear regression were used to identify central markets as the ones displaying a greater predicted value than the observed one. The size of the regression residuals, in combination with the results from the correlation analysis, were used to identify key markets and define their functional roles within the network.

Cohesive analysis

The overall network connectivity and structural features of the network were explored by carrying out successive cohesive sub-group analyses. First, a core-periphery analysis (Puck Rombach et al. [2014]) was carried out to identify densely-connected core nodes and sparsely-connected periphery nodes. We then assessed the distribution of components present in the network and identified the largest connected components.

In this analysis, components represent subgroups of nodes that are maximally connected between each other. However, components may be of two types: accounting (or not) for the direction of links in the network components may be either “strongly” and “weakly” connected. Strong components are subgroups of nodes in which a node can be reached from every other considering the directionality of links, whereas weak components are subgroups of nodes for which directionality of the links is disregarded. The size of the largest, also named “giant”, strongly (GSCC) and weakly (GWCC) connected components were then computed. It is worth noting that GSCC and GWCC are also considered as proxy measures for lower and upper bounds of maximal epidemic size, respectively, for epidemics spreading in the considered network (Kao et al. [2006]; Kenah and Robins [2007]; Volkova et al. [2010]).

Finally, we explored the distribution of communities present in the network. While components analysis uncovers nodes that are reachable following a contact path, communities detection identifies sub-groups of nodes densely connected to each other but sparsely connected with nodes in other communities. The number and composition of node communities were characterised using the Rosvall and Bergstrom, or Infomap, community detection algorithm (Rosvall and Bergstrom [2008]; Lancichinetti and Fortunato [2009]; Moradi et al. [2012]). This method, also called “maps of random walks”, is a flow-based clustering approach using a random walk as a proxy for the flow on a network to identify the shortest of the random walks on the network to reveal its community structure.

5.2.5 Network vulnerability and resilience

A percolation analysis was implemented to assess the vulnerability of the network to the targeted removal of nodes. This analysis consisted of measuring the impact of progressively removing nodes, one after another, in the decreasing order of a given node centrality measure, on the structure of the network. In this analysis, it could be considered that the removal of nodes consisted of implementing trade restrictions, vaccination or further animal testing, which would prevent disease to be transmitted to other nodes and spread (Jeger et al. [2007]). In this context, the resilience and the vulnerability of the cattle trade system in Cameroon to the targeted manipulation of the structure was assessed upon the cohesiveness of the network, thereby mimicking the impact of focused interventions on the network. Here, the cohesiveness of the network was measured in several ways, by computing at each removal step the sizes of the GSCC, of the GWCC and of the biggest community in the cattle trade network, as well as the total number of communities present in the remaining networks. Node centrality measures used in the analysis to drive the removal processes were *in-degree*, *out-degree*, *betweenness* and *eigenvector* and of the results from the key-actor analysis.

To better assess the impact of targeted interventions over the network connectivity the structural vulnerability of the network to strategic removal of central nodes was compared with the random removal of nodes. The targeted removal driven by the different centrality measures used in this study, including the results from the key-actor analysis, was compared with the median and the 95% range of 1000 simulations of random removals. Additionally, interventions targeting the most critical markets in the network functionality, as identified by the key-actors analysis, were compared with approaches targeting markets belonging to the top 10th percentiles of each centrality measure.

All analysis and graphics were performed in R statistical software (R Core Team [2013]) using the *igraph, tnet, fitdistrplus, glm, raster, rgdal, circlize and ggplot2* packages.

5.3 Results

5.3.1 Summary statistics and general network properties

Over the annual period, between September 2013 and August 2014, 252,831 individual cattle were traded and moved through the 127 markets identified in the study. Figure 5.3 shows the organic and heterogeneous structure of the network with all the Regions of the country being interconnected and with various trading links with neighbouring countries. The Adamawa and Central Regions of Cameroon have the most heterogeneous cattle movements structure, displaying connections with several other Regions and with neighbouring countries. The Adamawa Region appears to be the main source of cattle of the country while receiving animals from neighbouring countries, such as Chad and Central African Republic. In contrast, the Littoral and Central Regions appear to be major receivers of cattle, getting animals from almost all the other areas of the country. Interestingly, the North-West Region appears to be more independent and isolated within the cattle trade network of Cameroon, particularly receiving few animals from others Regions.

Due to the constant weekly nature of the market chain, all nodes were consistently part of the network over the year, with little variation in network connectivity between seasons. The number of links ranged from 328 during the rainy season (May to September), to 333 in the dry season (October to April). For the whole 12-month period, the network included 335 links (Figure 5.4). The main variation between seasons was related to the average number of animals traded per month between markets (Figure 5.5): on average, the number of traded cattle during the rainy season was 1.1 times greater than that traded during the dry season. Nevertheless, the greatest number of traded cattle was recorded in December (Figure 5.5). Over the entire study period, both network-level and node-level metrics showed little variation between seasons. As such, subsequent analyses were carried out over the annual aggregated network.

The network displayed a low *density* (0.021) of connections, with only 2.1% of the possible links present. The *reciprocity* of the network was 0.151, indicating that just 15.1% of the connections among markets were reciprocal, or bidirectional. The *degree assortativity* was -0.06: such a negligible negative value indicates a minimal tendency for markets to preferentially connect with markets of different *degree* centrality. A minimum of eight steps were required for connecting the two most distant reachable nodes, as measured by the network *diameter*. The visualisation of the actual path of the *diameter* showed that it extended from Chad, across the Adamawa Region of Cameroon ending in the North-West Region at the border with Nigeria (Figure 5.6).

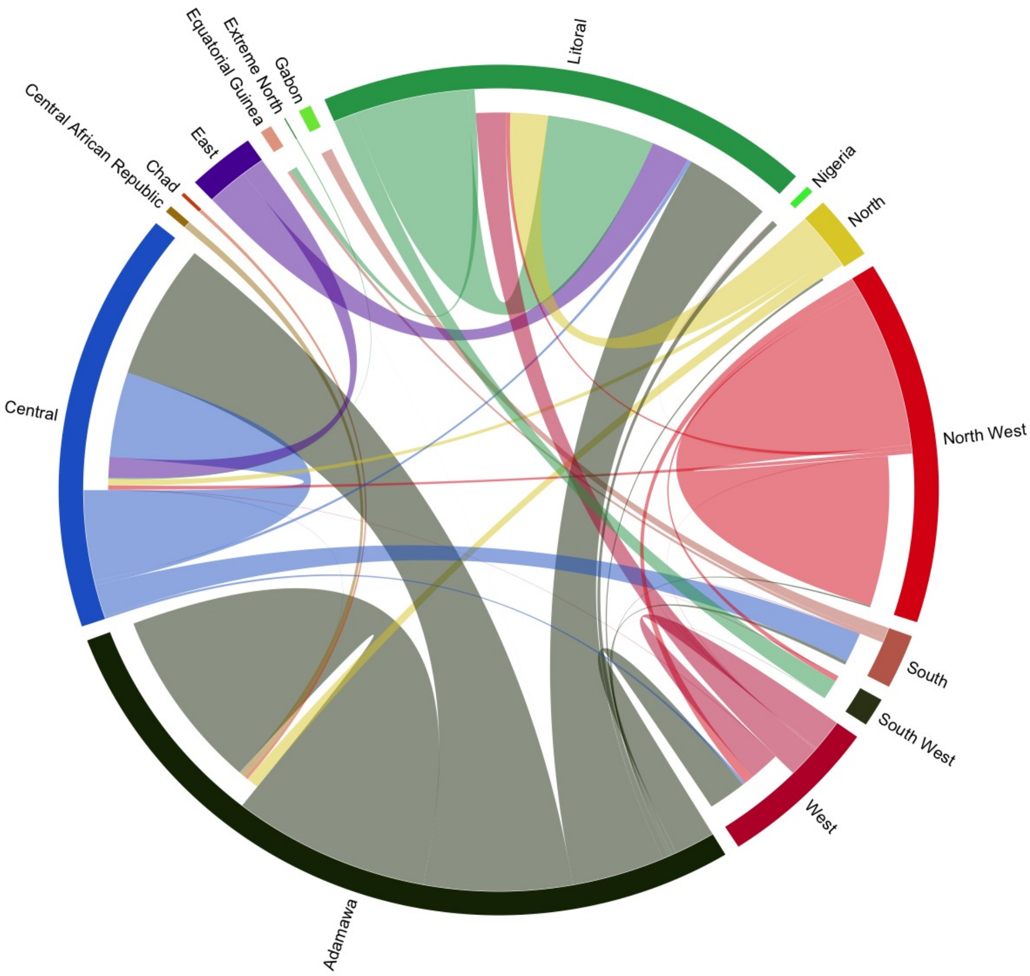

Figure 5.3: **Cattle flow in the livestock market system in Cameroon.** The origin and destination of traded cattle are represented in this circular map. Each sector of the circle represents a Region of Cameroon or a neighboring country involved by the cattle flow in the region. Outgoing animal flow starts from the base of each sector while received movements do not reach the base of the relevant sector. For instance, the North-West Region, in red, trades most of its animals within the same Region and only very small proportion of them are moved to the Littoral, Central, West and South-West Regions of Cameroon or are introduced from the Adamawa Region.

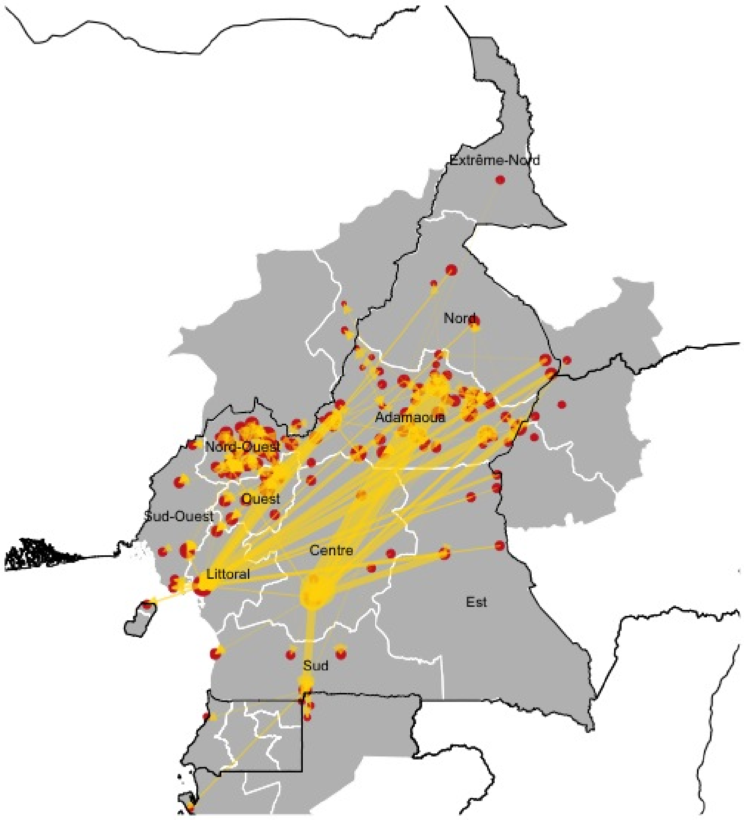

Figure 5.4: **Cattle trading network in Cameroon and neighbouring areas.**
Node sizes in the map are weighted by the relative value of eigenvector centrality. Ties show the direction of the cattle movement as indicated by the arrows and the proportional volume of traded animals is indicated by the thickness of the arrow.

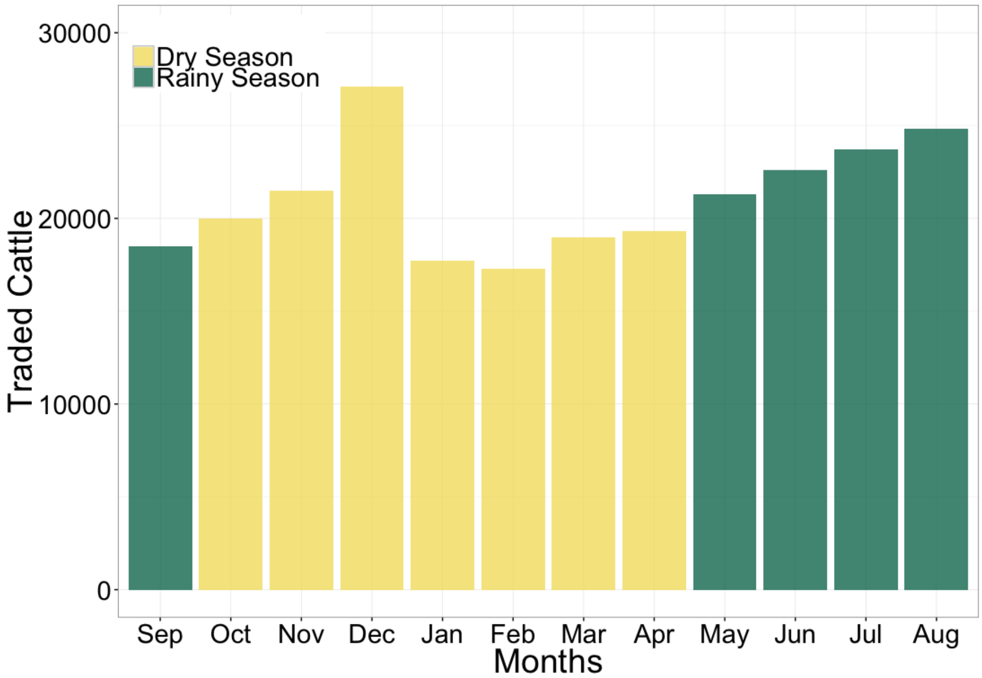

Figure 5.5: **Volume of cattle traded through the network of markets by month over a 12 month period.**
Green bars refer to the rainy season (May to September) while yellow bars refer to the dry (October to April). Between September 2013 and August 2014, a total of 252,831 cattle were moved through the cattle markets network.

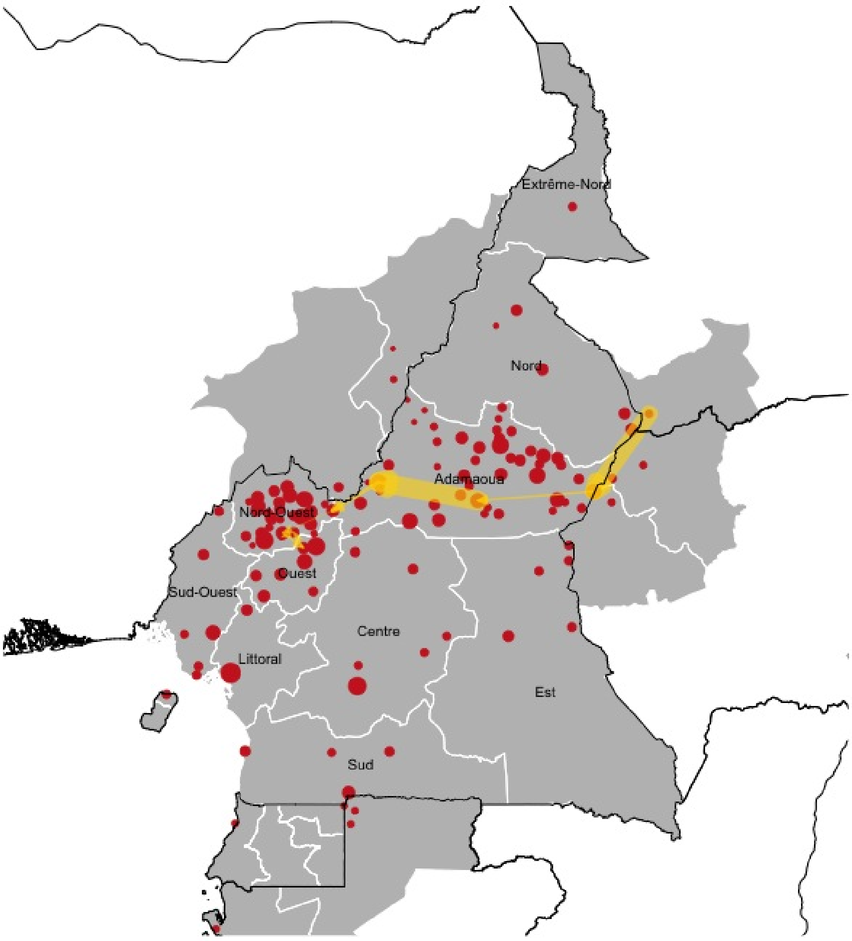

Figure 5.6: **Diameter of the trade network.**
The pathways between the two most distant reachable markets in the network is extending from Chad through Central African Republic, crossing central Cameroon, passing close to the Nigerian border and ending in the North-West Region of Cameroon.

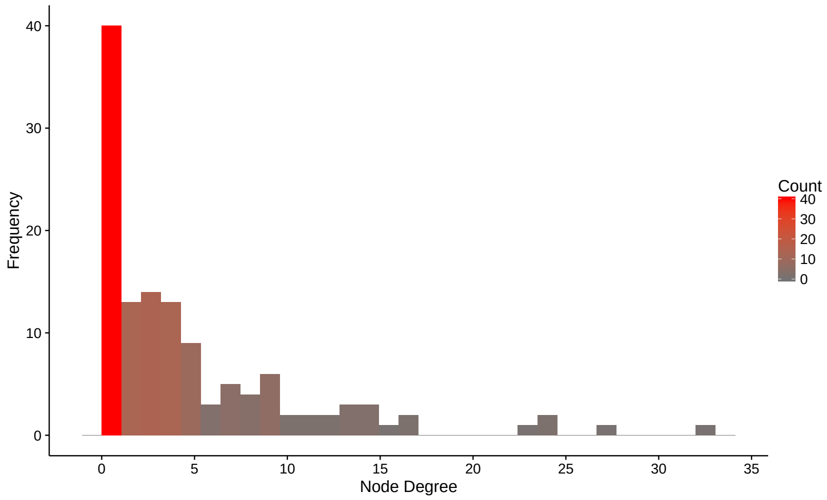

Figure 5.7: **Degree distribution of the livestock trade network.** Degree distribution for the 127 livestock markets included in the network.

Network topology

The *average path length* and the CC of the empirical cattle trade network in Cameroon were 3.07 and 0.25, respectively. In comparison, the mean *average path length* of 1000 simulated random networks was 4.74 (range = 4.39-5.38), whereas the 90th percentile of CC was below 0.05, five times lower than the empirical cattle trade network. These network characteristics are consistent with a small-world structure 41, 42. On average, markets were connected to 5.2 others (range 1-33), with 3.2 average incoming (range 0-29) and 2.6 outgoing (range 0-11) connections. The degree distribution for all markets involved in the cattle trade network was right-skewed with only a small proportion of markets being highly connected (20% of the markets held 58% of the connections, while 80% of the markets held the other 42% connections) (Figure 5.7).

5.3.2 Key-actors analysis

All the studied centrality measures, *in-degree* and *out-degree*, *eigenvector* centrality and *betweenness* centrality were strongly positively correlated (Spearman correlation r >0.7) (Table 5.2.). The smallest correlation coefficient resulted between *eigenvector* centrality and *betweenness* centrality (r = 0.70) and was applied to detect markets not having a linear relation between these metrics. Ten markets were identified as critical in the network: four were defined as the nucleus for structural functionality of the network ("pulse-takers"), four as being fundamental in connecting parts of the network that would otherwise be isolated from the network ("gate-keepers"), and two markets as having both these attributes (Figure 5.8).

Table 5.2: Correlation coefficients between nodes centrality measures.

	Betweenness	Degree	Eigenvector
Betweenness	1	0.8078	0.7087
Degree	0.8078	1	0.8879
Eigenvector	0.7087	0.8879	1

5.3.3 Cohesive analysis

The cattle trading network of Cameroon was organised around five cores (respectively 23, 18, 16, 16 and 13 nodes) and involved a periphery of 41 markets that were connected to the different cores (Figure 5.9).

All 127 markets involved in the network were included in the giant weak component. In contrast, 98 strongly connected components were identified. Of these strong components, 88 contained only one node, nine ranged between two and seven, while the largest included 11 markets, located in both the Adamawa and North Regions of Cameroon and representing, therefore, 10% of all markets (Fig-

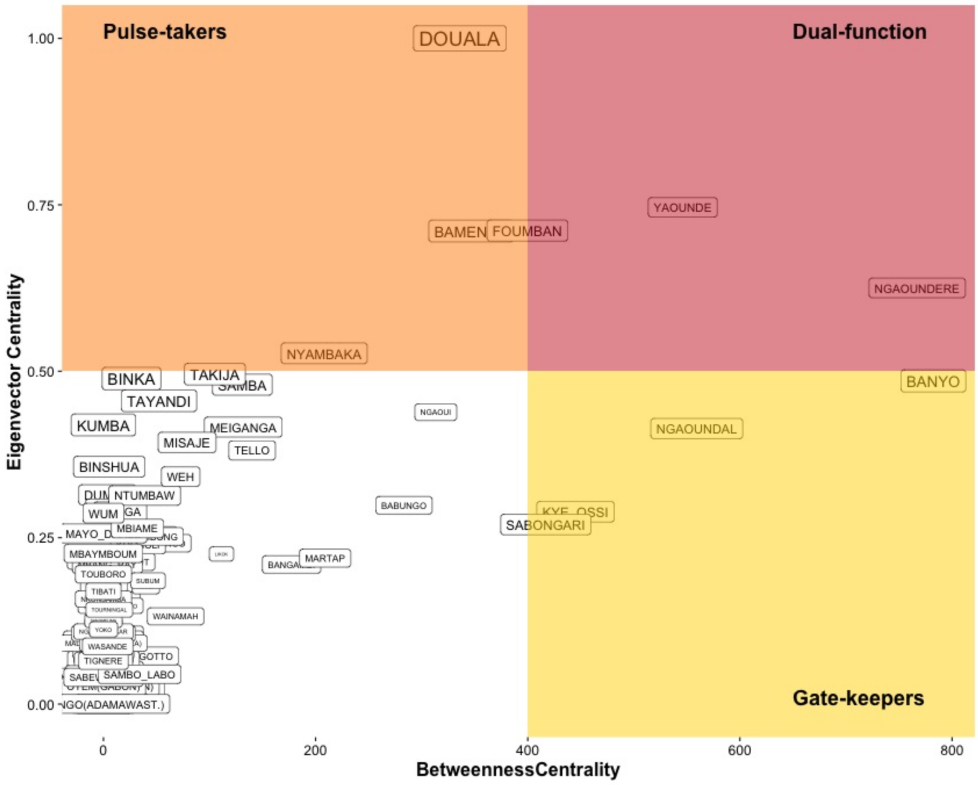

Figure 5.8: **Key-actors analysis on the markets network.** Correlation between eigenvector centrality and betweenness centrality is identifying markets with different roles within the trading network. “Gate-keepers”, in the bottom-right quadrant, are central entities in terms of their ability to bridge between the functional nodes of the network and wider community of nodes. In the top-left quadrant, “pulse-takers” are the nodes with the shortest paths to all other nodes having easy access to the other central markets as well as to the rest of the network. Nodes in the top-right quadrant have both abilities. Markets in the bottom left quadrant tend to have no particular role. The size of the labels is relative to the value of their residuals obtained through linear regression of betweenness over eigenvector centrality, indicating the extent of their deviation from a linear relationship.

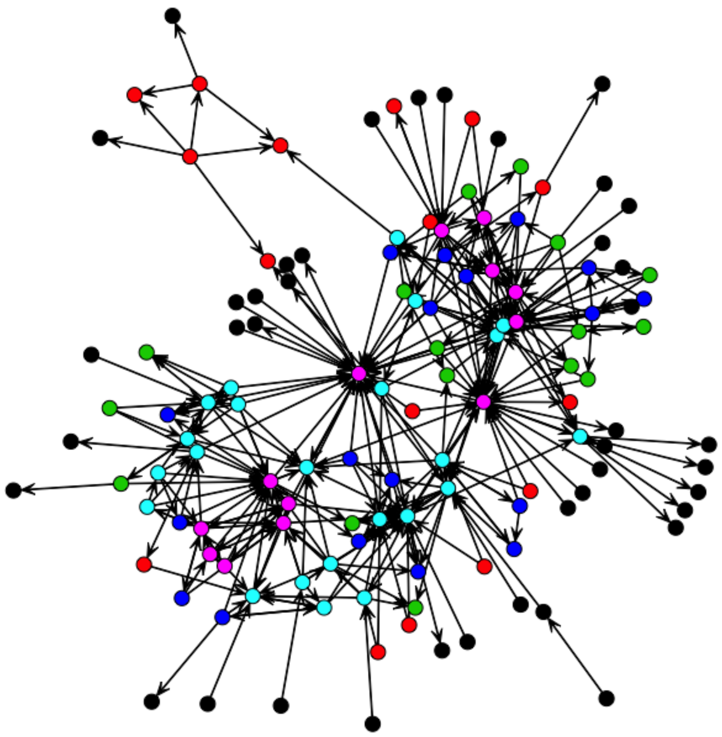

Figure 5.9: **Core-Periphery structure of the livestock trade network.** The periphery of the network included 41 markets (in black) while 5 cores composed of respectively 13 (pink), 24 ,26 ,19 and 22 markets were identified.

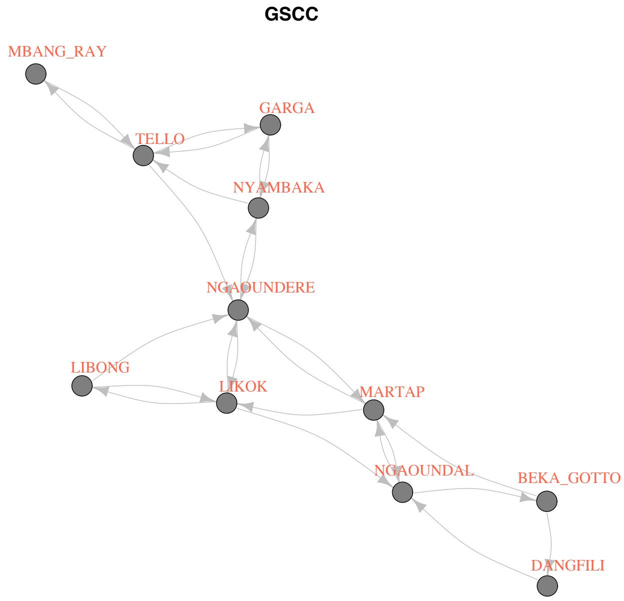

Figure 5.10: **Giant strong connected component of the livestock trade network.**
The GSCC included 11 livestock markets mainly located in the Adamawa Region, and one in the North region of Cameroon.

ure 5.10).

When looking at the community structure of the network, 15 communities were identified within the network. Each community included between two and 19 markets. The two largest communities included 19 markets each, therefore accounting for nearly 30% of all markets. The largest community included markets located in four Regions of Cameroon (Adamawa, Central, North-West and West) and a market in the Taraba State of Nigeria. The second largest community involved 18 markets within the North-West Region and one market in the South West Region of Cameroon, thereby confirming the cohesion and relative isolation of the North-West Region of Cameroon (Figure 5.11).

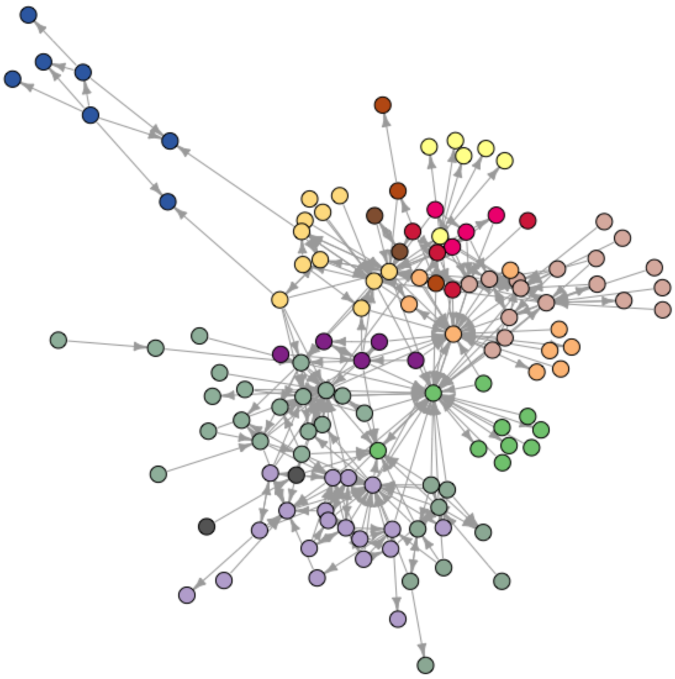

Figure 5.11: **Communities of the livestock trade network**
The 15 different nodes communities are highlighted with different colours.

5.3.4 Network vulnerability and resilience

Results of the percolation analysis on the cohesion of the network structure are shown in Figures 5.12 and 5.13. Removing markets based on their centrality measures resulted in notably faster changes in network structure than randomly targeting markets: with a faster reduction in the size of the GSCC, GWCC and the biggest community, as well as a faster increase in the number of communities involved in the network. Removing markets in the order of their values of *betweenness*, *eigenvector* and according to the key-actor analysis were the most effective strategy to fragment the GSCC: targeting around 20% of the most central nodes reduced the size of the GSCC by approximately 80% (Figure 5.12A). While *betweenness* and the results of the key actor analysis seemed to be slightly more effective during the early stages of disruption, *eigenvector* was overall leading to a more effective fragmentation at later stages (Figure 5.12B). *Eigenvector*, *betweenness* together with *in-degree* were also the most effective in disrupting the GWCC reducing its size by about 90% through the removal of around 20% of the nodes (Figure 5.12B). The size of the biggest community was reduced by about 70% through the removal of around 25% of nodes driven by *eigenvector*, *betweenness* and *in-degree* (Figure 5.13A). Node removal driven by these same metrics triggered the highest fragmentation of the network leading to a four-fold increase in the number of communities targeting around the 25% of the markets (Figure 5.13B).

5.4 Discussion

The presence of formal livestock traceability systems currently enables the description of livestock trade networks in numerous high income countries. This

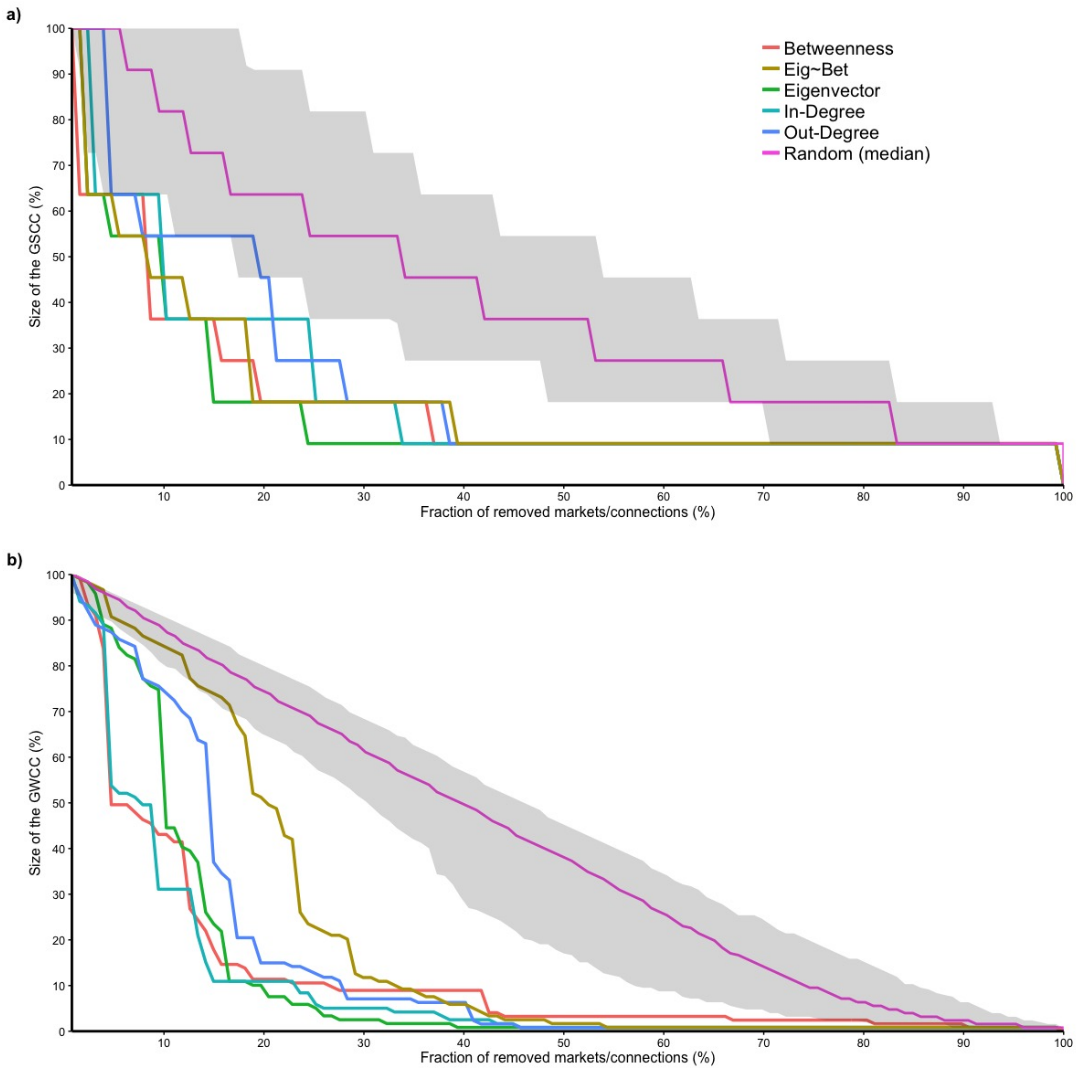

Figure 5.12: **Effectiveness of targeted removal of nodes and connections over the GSCC (a) and the GWCC (b) in the cattle trade network.** The y axis shows the size of the largest strong (a) and weak (b) component expressed as a percentage and the x axis shows the percentage of nodes, or connections, removal from the network. The effect of node removal, driven by the different centrality measures on the fragmentation of the components, is shown by the different colours: betweenness centrality in red, eigenvector in dark green, in-degree in light blue, out-degree in purple and the residuals from the regression of betweenness over eigenvector centrality in light green. Effect of link removal depending on their edge betweenness scores is showed by the light orange line. Random removal of nodes over 1000 simulations is showed with the median value (pink line) and its 95% range (grey shaded area).

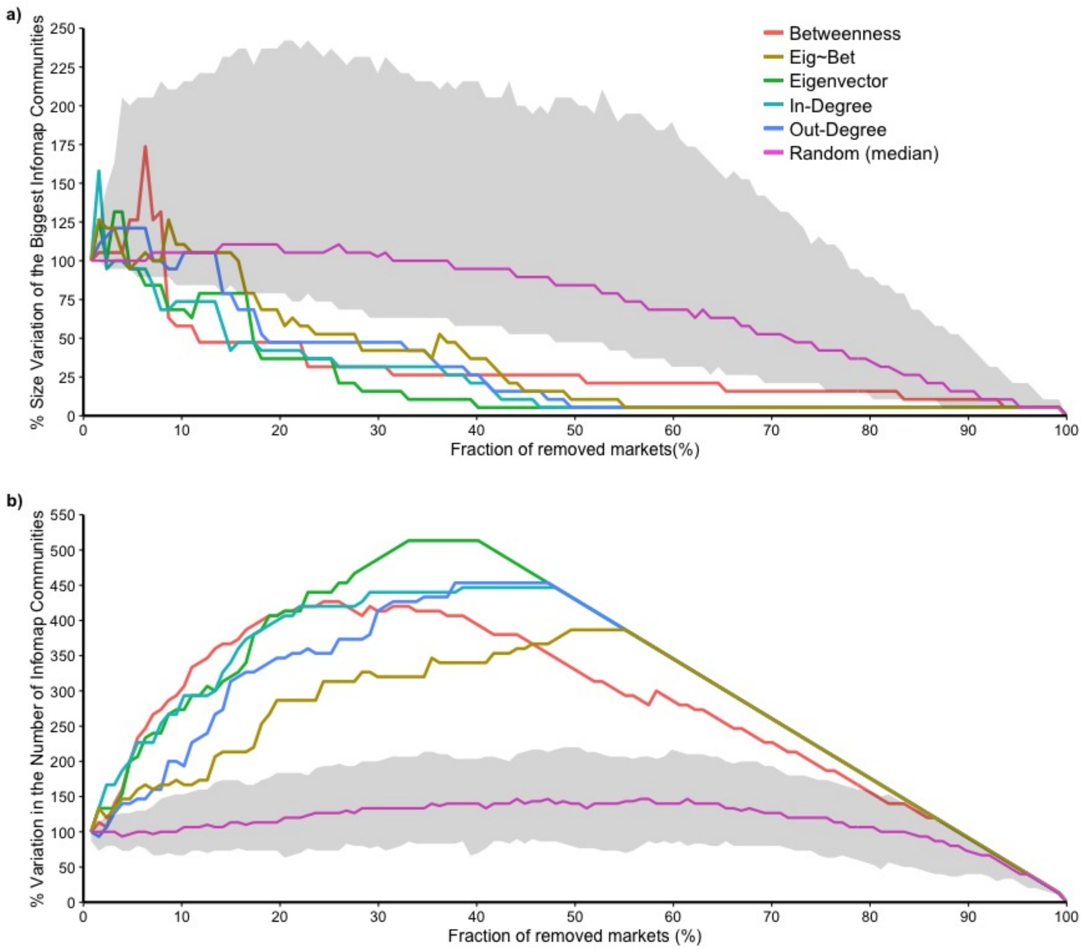

Figure 5.13: **Effectiveness of targeted removal of nodes over the size of the biggest communities (a) and over the number of communities (b) in the cattle trade network.**

The y axis shows the percentage variation in the size of the biggest communities (a) and in the number of communities (b) of nodes within the network and the x axis shows the percentage of node removal. The effect of node discharge, driven by the different centrality measures on the number of communities present in the network, is shown by different colours: betweenness centrality in red, eigenvector in light orange, in-degree in light blue, out-degree in purple and the residuals from the regression of betweenness over eigenvector centrality in light green. Random removal of nodes over 1000 simulations is shown by the median value (pink line) and its 95% range (grey shaded area).

information provides the opportunity to investigate the features associated with livestock movements and disease spread, improving animal health monitoring and surveillance systems (Keeling and Eames [2005]; Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Rautureau et al. [2011]; Guinat et al. [2016]; Relun et al. [2016]). In lower income countries, however, the structure and dynamics of livestock trade networks are still poorly understood due to restricted availability of data (Tempia et al. [2010]; Dean et al. [2013]; Vallée et al. [2013]; Fournié and Pfeiffer [2013]; Molia et al. [2016]).

In this chapter, it is described for the first time the network of cattle trade between markets in Cameroon, evaluating key markets and showing that markets in both neighbouring and non-neighbouring countries are epidemiologically connected via long-distance and cross-border cattle trade routes.

Over the study period, a seasonal pattern was seen in the flow of cattle in the network, with more cattle traded during the rainy season (that is between April and August) than during the dry season. This pattern is likely due to the higher abundance of pasture during the rainy season, allowing animals to be fatter and therefore more marketable. However, the high volume of cattle traded in Cameroonian markets in December, despite being in the middle of the dry season, suggests that traditional behaviours and religious celebrations at the end of the year could be an important factor influencing the demand for animals on the market. Nevertheless, there was little variation in the structural characteristics of the cattle trade network as well as in its properties across seasons, showing that, despite the seasonality in traded numbers, the network of cattle moving between markets in Cameroon is very stable. The consistent structure of the network over the year increases the robustness of targeted interventions to temporal variations.

This study has characterised the Cameroonian cattle trade network as a compact network with multiple subgroups of markets which are interconnected through the presence of a few long distance connections typical of a small-world network. In addition, any two markets in the cattle trade network of Cameroon were reachable through an average of 3.1 steps, whereas only eight steps (as informed by the network *diameter*) were necessary to get from one side of the network to the other. While small-world networks are known to ease the spread of infectious diseases, thereby favouring rapid dissemination of pathogens through the network (Keeling and Eames [2005]; Shirley and Rushton [2005]; James et al. [2009]; Dubé et al. [2011]) such a small network *diameter* is of concern. Examining the actual pathway of the *diameter*, which extends from Chad to Nigeria through the Adamawa and North-West Regions, it is clear that there is a potential direct connection between non-neighbouring countries, allowing diseases to spread rapidly across the region. These findings highlight that neither large geographical distances nor national boundaries represent a barrier to the dissemination of infectious diseases in this part of Africa. In this context, national strategies are likely to have limited effectiveness if developed alone and in isolation and that regional coordination for designing and implementing prevention and mitigation strategies against infectious diseases is essential to improve animal health in SSA.

Nevertheless, the cattle trading network in Cameroon is heterogeneous and organised around regional clusters of trading behaviours. As a major cattle production area in Cameroon, it is not surprising that markets from the Adamawa and Central Regions are highly connected with the rest of the country and with the neighbouring countries, forming not only the largest community of contacts of the cattle trade network but also including 10 out of the 11 markets involved in the GSCC. In contrast, the North-West Region of Cameroon was found highly isolated to the rest of the network, with cattle preferably moving between markets within this region and forming a large community of contacts. Nonetheless, a few incoming and outgoing trade connections with other areas of the country or with foreign countries allowed markets of the North-West Region to remain connected with the rest of the network. These findings suggest that the Adamawa and Central Regions may be at higher risk for disease incursions and rapid dissemination over long distances, while the North-West Region could be more protected from the introduction of external threats, however, being more prone to a rapid local dissemination of pathogens. This Region, therefore, may also provide a more manageable setting for piloting the efficacy of surveillance or control measures compared with other Regions of the country.

The targeted removal of highly connected nodes is considered an effective method to identify nodes where the implementation of intervention measures for surveillance and control strategies, such as implementing trade restrictions, vaccination or animal testing, would be most efficient (Kiss et al. [2006]). Here, we found that targeting the top 20% of the most connected markets (as defined by their *eigenvector*, *betweenness* centrality and the outcome of the key-actors analysis) would significantly reduce the network cohesiveness, regardless of the pathogen being directly transmitted between markets via animal movements or indirectly through personnel, vehicles or infrastructures. Although these findings provide opportunities for targeted disease risk mitigation interventions based on these connectivity measures, such a strategy may be difficult to implement on the ground. While market closure has been suggested as a highly effective strategy in interrupting the dissemination of an infection over the network (Fournié and Pfeiffer [2013]), such a mitigation approach could potentially lead to unintended effects. Particularly, the potential severe damages in profits, for both private and public stakeholders, due to the closure of important trading markets may create novel pattern of cattle movements (either legal or illegal) within the country. The resulting rewired cattle trade network could lead to an increase in the risk of disease dissemination as well as to reduce the control of the veterinary services over cattle trade patterns.

Alternative disease risk mitigation interventions could be the implementation of increased bio-security measures, introduction of preventive emergency vaccinations for high risk animals in combination (or not) with quarantine measures, and movements bans for cattle originating from high-risk areas. These have the advantage to conserve the pattern of cattle trade network while requiring limited technical and financial resources as well as ensuring the collaboration of all actors of the cattle industry in Cameroon.

Targeting key markets as part of surveillance strategies has the potential to increase the detection sensitivity of diseases, particularly compared with randomly implemented interventions. Improving early detection of diseases would decrease the risk of importing, spreading and exporting infectious diseases at a local and regional level. Simultaneously, could increase cost-efficiency of interventions enabling better allocation of resources for animal health interventions. It is worth noting that targeting key markets of the cattle trade network for communication and training campaigns has the potential to raise the awareness of stakeholders present in these markets regarding infectious diseases risks and livestock management practices. Raising awareness could then ideally facilitate the involvement of market stakeholders (i.e. farmers, herders, traders) in a systematic reporting scheme on animal health, and related aspects. This would strengthen the current passive surveillance and increase the sensitivity of the early detection and communication of outbreaks, or other relevant events. Such a framework could be especially important for key priority livestock and zoonotic diseases in the country as identified by the study in chapter 4 of this thesis. Dermathophilosis, FMD and trypanosomiasis are major infectious diseases affecting cattle traded through livestock markets in Cameroon, however, other also CBPP, bTB and LSD are not uncommon.

In Cameroon, as in most of SSA, traders (known locally as "buy'm sell'm") whose primary activity is dealing cattle between markets, are key actors in the cattle marketing system. Commonly, traders buy and sell cattle locally or regionally, visiting markets within a relatively restricted area and most cattle movements still occur on foot and in order to limit expenses and optimise their profits. In a minority of cases, however, some traders are known to buy larger numbers of cattle at sub-regional and regional markets to sell at national primary markets (located near major urban areas). In both situations, however mostly at local and sub-regional markets, individual animals are not always all immediately sold when presented at the market. Some of those unsold animals may move back to the herd of origin (i.e. "escorting cattle") or be sold at the same market, or another market, on another sale day or to another market. In this study, the cattle trading network between markets in Cameroon was informed by the official market records of cattle transactions (purchases and sales). As such, it is reasonable to believe that the number of animals moving from and to markets may be slightly underestimated, which may have affect some of the results. This limitation is, however, mostly related to the number of traded cattle. As the structure of the trading system has shown to be very stable in Cameroon across the year and, the number of trading connection over the year are likely not to have been affected by this data limitation. Furthermore, studies on the effects of incomplete information on the properties of empirical networks have shown that *eigenvector* centrality and *in-degree* were robust to incomplete information, even when 50% of the data were missing, providing confidence in the results of this study (Costenbader and Valente [2003]).

This study aimed to describe and analyse the livestock trade network in Cameroon. However, it was not possible for security reasons to physically visit and sample the North and Extreme North Regions of the country. As such, we are aware that this study missed an established direct pathway of cattle trade, known to flow from high livestock production regions in Central Africa towards countries with a high demand of animal and animal products in West Africa passing through the Extreme-North Region of Cameroon. In this study, we focused on the movement of cattle among markets, regardless of the type of cattle moved. However, there are additional pathways that may determine pathogen transmission between markets, including movements of other animals, people and vehicles. By focusing on the trading system we only targeted the formal cattle movements in the country missing the role of the informal seasonal cattle transhumance and underestimating the scale of both the across-country and cross-border cattle movements, and the more organic and complex nature of livestock interactions at a local, national and regional level.

In settings where there is still restricted information on livestock movements, formal quantitative approaches based on empirical observations and analyses are increasingly needed to understand the interactions between livestock production and trade systems, pathogen transmission and the wider environment. As the design of risk-based surveillance systems and of control and communication strategies increasingly requires prior epidemiological knowledge, this study aimed at providing the baseline for more effective evidence-based decisions and interventions for diseases where live animal trading constitutes a major risk for disease introduction and dissemination.

5.5 Conclusion

The major outputs of this study show that the cattle trade network in Cameroon (1) is very stable throughout the year connecting neighbouring and non-neighbouring countries, (2) has a very clear small-world structure with long distance connections and clustered areas which are isolated to others, and (3) presents the opportunity for targeted surveillance, control and communication interventions. In this context, national strategies are likely to have limited effectiveness if developed alone and regional coordination for designing and implementing prevention and mitigation strategies against infectious diseases is essential. Despite the limitations of the present project and the need for further studies on cattle population dynamics in the region, the identification of key livestock markets and long distance interactions as well as the characterisation of the various roles of the Regions of Cameroon within the cattle trade system could offer the opportunity for “intelligent tracing”, applying empirical knowledge to infectious disease communication, surveillance and prevention.

Chapter 6

Drivers of cattle prices in the Adamawa and West Regions of Cameroon

6.1 Introduction

In Cameroon the livestock sector contributes 20% of the agricultural GDP, with trade of live animals and livestock products representing a major component of the agricultural sector (Pamo [2008]). As in most of SSA, livestock production is particularly important for people in rural areas, providing year-round employment opportunities and a key source of revenues (Delgado et al. [2001]; Thornton [2002]). Notably, the sale of livestock, mainly cattle, is a rapid cash generating mechanism (Little et al. [2001]) that allows purchasing food and family necessities (Thornton [2002]; Todaro and Smith [2014]) as well as representing a source of self-insurance against income shocks caused by unforeseen events impacting rural households (Todaro and Smith [2014]). Livestock value, therefore, represents a key asset for reducing the vulnerability of rural households to a number of external factors, such as climate change, animal diseases and social and political instability. Nevertheless, the risk mitigation strategies available to these households for coping with the effects of external factors on livestock value are generally weak and inadequate (Todaro and Smith [2014]). Animal diseases, in particular, generate a wide range of direct and indirect socio-economic impacts on rural and urban households (Thornton [2010]). Nevertheless, difficulty in assessing and measuring these impacts, particularly in SSA, are often caused by the lack of data and their adequate understanding and application (Perry et al. [2013]).

Various studies have been carried out in Cameroon to evaluate the burden of livestock and zoonotic diseases (Bronsvoort et al. [2003]; Bronsvoort et al. [2004a]; Awa and Ndamkou [2006]; Awa and Achukwi [2010]; Scolamacchia et al. [2010]; Handel et al. [2011]; Egbe et al. [2016]), identify constraints for disease control in pastoral and small-scale livestock husbandry and production systems (Kelly et al. [2016]) and better understand how the cattle trade is structured (this current Thesis). Together, these studies provide a collection of information which would enable the veterinary services to better design surveillance, prevention and control strategies for animal-health in Cameroon. Knowledge of livestock value represents a key information for estimating the impact of infectious diseases both in terms of direct and indirect losses (Knight-Jones and Rushton [2013]), for assessing the cost of control strategies (Bradbury et al. [2017]), as well as for contingency planning and risk assessment for national veterinary services. However, it is complex to evaluate the socio-economic impacts of veterinary intervention strategies and their implications for national and household economies with little or no knowledge of the value of livestock and of the factors affecting their trade. Better understanding livestock price formation and its drivers is therefore critical for designing and implementing efficient and robust, evidence-based interventions for animal health management.

The lack of a reliable price information system is a common constraint on livestock marketing both in the pastoral and urban areas across most SSA (Pavanello [2010]; Onono et al. [2015]). Studies in other regions of the world, notably in Northern and Southern America, have shown that a number of factors affect the price of cattle along the marketing process, such as physical, genetic and nutritional characteristics, as well as handling and market conditions (Troxel and Barham [2007]; Christofari et al. [2010]; Koetz Júnior et al. [2014]). In intensive and semi-intensive cattle rearing systems animal price tends to be affected by muscle scores, weights, diet as well as breed for an example (Christofari et al. [2010]; Koetz Júnior et al. [2014]). Studies in SSA have focused primarily on understanding price variability over time, in particular assessing how price respond to environmental and ecological variability, such as droughts and pasture availability, and to shifts in export and meat demand (Fafchamps and Gavian [1997]). In SSA, periodic events such as religious festivities and national celebrations, are also known to impact the fluctuations of livestock price over time (Barrett et al. [2003]). Therefore, the current understanding of the effects of animal characteristics and of local and national factors on price formation of cattle in SSA is still limited and inadequate for designing pricing procedures and policies to improve the livestock marketing system.

Up to now there has been very limited empirical information on determinants of market prices of cattle also in Cameroon. Understanding key aspects contributing to price formation within the cattle trading system in some of the major livestock production areas of Cameroon could also enhance the knowledge of the dynamics and of the drivers of commercial movements of livestock. This inadequate understanding also affects the ability of evaluating economic impacts and viability of different strategies for disease surveillance and control, as for instance incentives and compensation schemes, and their effects on the livestock sector. This knowledge is also increasingly needed as the demand for animal and animal products in the region is projected to expand in the short-medium term, as well as the volumes of cattle trade and the associated trading movements (Alexandratos and Bruinsma [2012]). As long-distance movements of animals are also known to be central drivers of infectious disease dynamics (Fèvre et al. [2006]), a better understanding of price formation would provide valuable knowledge for more evidence-based decision making also for livestock disease management strategies and interventions.

In most of the Adamawa and some part of the West Regions, prices and movements information are routinely recorded at livestock markets for each transaction (together with some characteristics of the animal traded) mainly for tax collection purposes. Once collected and centralised in a unique data set, these records represent a unique resource for better understanding the factors that drive prices of live cattle in the Cameroonian trade system. In this chapter, we used this collection of market records to evaluate which factors contribute to cattle price at the market level within the livestock trading system in some of the major livestock production areas of Cameroon. Specifically, we developed a generalized additive mixed-effect model (GAMM) and applied an information-theoretic approach derived from the ecology literature (Burnham and Anderson [2004]) to identify factors (as well as evaluating their robustness) impacting on the value of traded cattle in Cameroonian markets.

6.1.1 Objective

The main objective of this study was to identify the key factors contributing to the price of live cattle at the market level within the livestock trading system of the major livestock production areas of Cameroon. In particular, cattle phenotypical characteristics, population distributions and markets features were tested. Ultimately, this information will improve the understanding of livestock price developments and their determinants in pastoral zones of Cameroon, as well as provide knowledge for more evidence-based assessments of the impact of animal health interventions.

6.2 Materials and Methods

6.2.1 Data collection (*R_1 and R_2*)

During each marketing day market staff in the Adamawa and West Regions of Cameroon routinely records this information in reporting ledgers, which are then stored in the local offices of the MINEPIA. For the details about the data sources see Section 3.3 of this thesis. Market transaction records (R_2 - Figure 3.3) with complete data on prices of traded cattle for the period between September 2013 and August 2014 were available from 31 cattle markets out of a total of 37 cattle markets identified in the study area (Adamawa and West Regions). Additionally, official monthly reports (R_1 - Figure 3.3), for the same period, were obtained from the competent sub-Divisional offices of the MINEPIA for each market considered in the study.

6.2.2 Outcome and predictor variables

Official reports (R_1) and market records (R_2) included the cattle price, recorded in Central African Franc (CFA), the sex and age of the traded animal, and date of the transaction.

A set of predictor variables was developed including the information from the official documentation obtained at the markets level (sex, cattle type, age, week of transaction, market and administrative Division), information relating to populations distributions (human and cattle densities), to the connectedness of the market in the trading system (market centrality) as well as the season in which the transaction was carried out (Table 6.1).

Additional predictors not available from the official documentation gathered were used to evaluate the drivers of cattle price in the study area was obtained from alternative sources. The connectivity and therefore the centrality of the market in the trading system was considered. In particular, the number of connections (*total degree* centrality), the directionality of the connections (*in-* and *out-degree* centrality), as well as the tendency of connecting otherwise disconnected markets (*betweenness* centrality) and of connecting to other highly central markets (*eigenvector* centrality) within the Cameroonian cattle trade network were considered in the current study (Chapter 5 of this thesis).

To account for the distribution of populations and their potential impact on the local demand and supply capacity for live cattle at each market, estimates of human and cattle population densities were extracted from raster datasets freely available on-line (FAO - NationsGeoNetwork Team [2005]; Linard et al. [2012]). For the purpose of analysis, we assumed that both cattle and human populations were stable overtime and could be extrapolated from historical, though recent, information. Data on cattle population density were extracted for the year 2005 from Gridded Livestock of the World (GLW) dataset, freely available at the FAO GeoNetwork repository (FAO - NationsGeoNetwork Team [2005]). Information on the human population density the year 2010 was obtained from the WORLD-POP data (Linard et al. [2012]; Noor and Tatem [2013]). In addition, the size of the market was defined by the total number of cattle traded during the 12-month observation period, while the seasons as dry (October to April) and rainy (May to September). This data were then combined (extracted by points) with the data originated from the official documentation (R_1 and R_2). For each animal included in the dataset, the centrality of the market it was sold at, as well as the cattle and human populations densities of the areas where the market was located were added as new variables to the master dataset.

6.2.3 Data pre-processing and cleaning

Data description and exploration

As a result of the data collection, a substantial pool of price records was available covering 118,017 cattle traded within the identified 31 cattle markets between the 1st of September 2013 and the 31st August 2014. The homogeneity of variance in the response variable was assessed by looking at crude estimates of variance. Data exploration of all the variables included in Table 6.1 was carried out using a mixture of plots (histograms, box-plots and scatter-plots), and simple statistical tools including summary data tables and correlation coefficients for checking for collinearity of continuous predictors. Assessment of co-linearity among the predictors enabled to identify high correlation (>0.4) among some of the proposed variables. Total, *in-* and *out-degree* centrality, as well as *betweenness* and *eigen-*

vector centrality were highly correlated (Section 5.3.2 of this thesis). Because *eigenvector* and *betweenness* centrality require a more complex calculation, and as the objective of this selection was to identify a simple metric that could be easily extracted from the data, the choice was restricted to *in*-, *out*-and total *degree*. Finally *in-degree* was chosen as conceptually we observed during the field work and the analysis of the matket transaction records that data on origins of the traded cattle are generally more consistently complete in comparison to the destinations. Additionally, market size was dropped from the model building due to the high level of correlation with *in-degree* centrality (>0.6). The data obtained from online sources showed different relations with the response variable. Human population had a linear relation with cattle price, and was then categorised into 3 categories (Table 6.1). Conversely, bovine population density showed a less linear relation to live cattle price and, therefore, was treated in the model with a smoothing univariate function as further explained in Section 6.3.2.

The week of the year that the price was recorded was made as an ordinal variable (Table 6.1). As for the cattle population density this explanatory variable did not show a linear relation with the outcome variable and, therefore, was treated in the model with a smoothing univariate function as further explained in Section 6.3.2. As price per animal was recorded as a sequence of measurements made at weekly intervals, we explored the relationship between subsequent weekly observations through autocorrelation analysis to assess how price was related to itself overtime.

Missing age and imputation

After this preliminary assessment it was necessary to run few pre-processing steps in preparation for the modelling, in particular for the imputation of missing

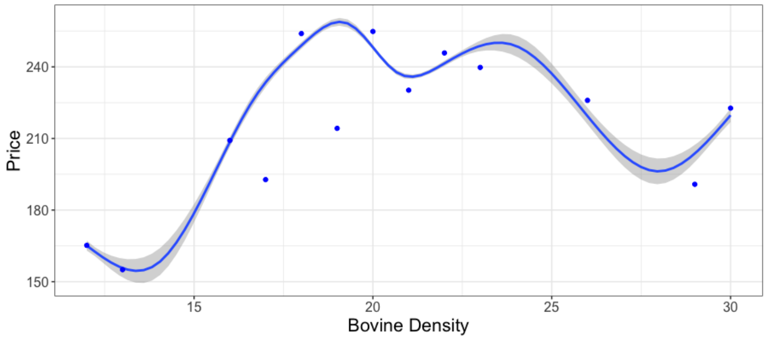

Figure 6.1: **Relation between cattle price and cattle population density.** On the y axis the price of the traded cattle and on the x axis the cattle population density in heads per squared kilometre. The blue line represents the smoothed line of the relation between the price of the 118,017 traded cattle and the estimated cattle population density in the local administrative unit for the year 2005 as obtained from the online FAO GeoNetwork repository.

age data. The market transaction records (R_2) showed a certain level of missing data, but only referring to the age of the traded cattle which was missing for about 25% of the observations. Missing values were mainly due either to lack of annotation in the market records (probably due to the short time available to report this information during the transaction), or to the unclear understanding of the hand writing in the records when transcribing the records in digital format. A variety of imputation approaches can be used to keep the full sample size. In this dataset missingness was limited to a single variable, animal age, while for other variables included in the market transaction records (R_2) the information was complete. These complete variables included the type of animal (steer, bull, cow, young bull or heifer), the month in which it was traded and the sale price of each animal.

Because for each recorded animal, including the ones with a missing age, complete observations of the other variables were available, it was possible to use a "matching" imputation approach (Gelman and Hill [2007]). To assign the age to the missing observations, each animal with a missing age was matched with an

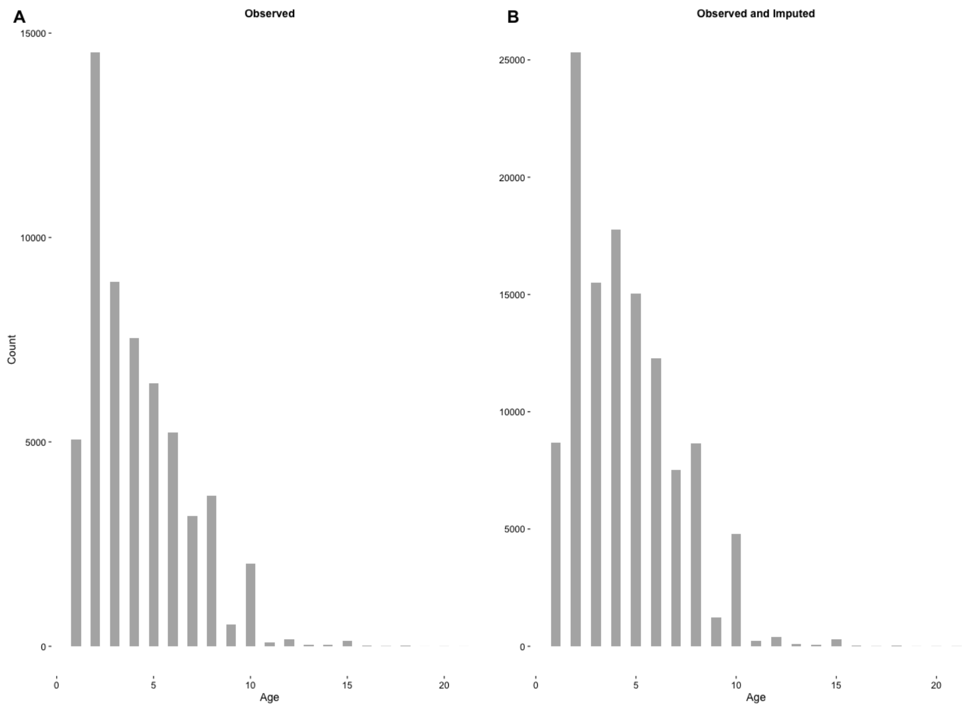

Figure 6.2: **Age distribution of traded cattle.**
A: age distribution of the incomplete dataset. B: age distribution after imputation of missing age in the dataset. The y axis ranges in A and B are in different scales as the intent of the figure is to control for the pattern of distribution of the data points.

animal of the same type (steer, bull, cow, young bull or heifer), sold at the same market, during the same month.

The distributions of the age of the incomplete dataset and of the dataset including the imputed observations were then compared (Figure 6.2). In general, traded animals were mostly young cattle below 4 years old, showing a peak at the age of 2 (Figure 6.1). These distributions showed a high level of consistency. Nevertheless, after imputing the missing ages a slight discrepancy in the distribution around 3 and 4 years of age appeared, most likely due to the restricted number of matching variables used for imputation. Additionally, Figure 6.2 shows that in both distributions there is a spike at 10 years old, which might represent a reporting problem as animals of around that age might have been approximated to ten years during the recording process at the market level. The age variable was then categorised into five levels with similar age intervals and approximately linear relationship between age and price (Table 6.1). To adjust for the slight discrepancy between observed and imputed age data, animals of 3 and 4 years of age were merged into the same age category (Table 6.1).

6.2.4 Modeling framework

Generalised additive mixed model

In order to account fo the non-linear relationships between the response and a set of explanatory variables (cattle population density and week of observation) a generalised additive modeling approach (GAM) (Hastie and Tibshirani [1990]; Burnham and Anderson [2004]) was applied to identify and assess animal and market factors that drive price formation and estimate their influence over cattle price variation. GAMs are a non-parametric generalisation of multiple linear regression that are also less restrictive in their assumptions about the underlying distribution of data and that can model non-linear relationships between the response and the set of explanatory variables (Maindonald [2010]).

Here the price of each i^{th} live cattle, Y_i, is assumed depending linearly on a set of k predictor variables x_k and on m unknown smooth functions f_m of non-linear predictor variables Z_m such as:

$$g(E(Y_i)) = \alpha + \sum_k \beta_k x_k + \sum_m f_m(Z_m) + \epsilon \tag{6.1}$$

where:

Table 6.1: Variables used to build the modeling approach of cattle price at the market level.

Variable	**Data type**	**Definition**
age	ordinal	A categorised variable with 5 levels (<2, 3-4, 5-6, 7-10, >10 years old)
sex	binary	Male or Female
season	binary	Dry season (October to April) and Rainy season (May to September)
Division	categorical	Names of the 6 Divisions: Djerem, Faro et Deo, Mayo Banyo, Mbere, Vina and Noun
cattle density	continuous	Density of cattle living in the administrative area of the market as extracted by the online repository varied between 0 and 30 animals per Km^2
human density	ordinal	Density of human living in the administrative area of the market as extracted by the online repository was categorised in 3 levels (low: 1-50, medium: 50-200 and high: >200 per Km^2)
market in-degree	continuous	In-degree centrality of the market in the cattle trade network in Cameroon (ranging from 0 to 16 incoming trade connections per market).
market	categorical	The ID of the 31 livestock markets (M1 to M31) where the report data were obtained.
week	ordinal	The week of the year that the report was made as an ordinal variable (from the 1st of September 2013 to the 31st of August 2014).
price	continuous	The price in local currency (CFA) of each traded cattle at the markets in the study area for the period between the 1st of September 2013 to the 31st of August 2014.

$g(E(Y_i))$ = is the linear function of the expectation of the price $E(Y_i)$

α = is the intercept

β_{k} = are the coefficient of the predictors x_k

f_{m} = are the coefficient of the predictors Z_m

ϵ = are the residuals

In this study both week of purchase and bovine population density in the administrative area of the market were found to have a non linear relation with cattle price and modelled using a smooth function. This was achieved by applying penalised regression splines for the weekly intervals of the recorded data and to the bovine population density.

The *k* predictor variables used in the modeling approach included animal characteristics, market factors as well as the season the transaction was carried out (Table 6.1).

Furthermore, to account for correlations generated due to repeated information from each market over time (weekly interval), *random effect*, U_j, was added in the model, a generalised additive mixed model (GAMM) such as:

$$g(E(Y_i)) = \alpha + \sum_k \beta_k x_k + \sum_m f_m(Z_m) + \ U_j + \epsilon \tag{6.2}$$

Model building

The size of the dataset offered the opportunity to assess the variability of the model fit, and to increase the confidence of its robustness. To increase the ability to evaluate the robustness of the model fit, manual stepwise selection was applied in combination with an iterative approach while building the model. This iterative approach has been suggested as more appropriate to assess the resilience of the model to different subsets of the dataset increasing the confidence in the model fit (Austin [2008]). By running multiple iterations over a dataset, or multiple subsets of the dataset, this iterative approach allows to compute the statistics on each of the iteration and, therefore, getting a distribution of these statistics.

In this study for each set of considered models, 50 iterations/sample of the model fitting were carried out. For each iteration, 10% of the data set were randomly selected with replacements from the original dataset. Each of these subsets were then used to fit each model, and then the performance outputs of these models for every iteration were computed (see the next subsection). This provided a set of goodness of fit measures that enabled the comparison of models and evaluation of resiliency and fitting to the data. A number of alternative models were assessed in order to select the best fitting and most parsimonious model, explaining the most variability in the outcome variable through the inclusion of the least parameters. The selection approaches followed the recommendations from the literature applying a manual stepwise dropping of explanatory variables and comparing tested models by using the Akaike Information Criterion (AIC) and the adjusted coefficient of determination (R^2) (Pinheiro and M. [2000]; Dohoo et al. [2009]) (see the next section for the description of the selection criteria).

Model selection

Model selection was carried out using the information-theoretic approach (Anderson and Burnham [2002]). This approach is derived from ecological theory and consist in fitting various combinations of the putative drivers together for multiple sampled subset of the data to derive the final model from the set of possible candidates. In this study, 50 bootstrapped samples of equal size (n=11,800) were randomly generated using a stratified approach from the testing data set (i.e. resampling the data with replacement). For all 50 subsets, 24 candidate models were considered and compared to identify the final model (Appendix B, Table B.1).

As recommended by Eberhardt [2003], fitting performance was evaluated based on the Akaike Information Criterion (AIC; (Akaike [1998])) and the adjusted coefficient of determination (R^2) (Pinheiro and M. [2000]; Dohoo et al. [2009]). The AIC provides evidence for which combination of variables best explained the data with the minimal number of covariates, whereas the adjusted R^2 statistic provides a more 'global' measure of how good the model is at explaining the data by measuring the amount of variance explained by the model. It is worth noting that both AIC and adjusted R^2 are measures that penalize for the number of independent variables in the model. As such, these statistics provide measures of support for the most parsimonious model. For comparison, the ΔAIC was also extracted for each tested model by computing the difference between each model-specific AIC and the highest AIC among all tested models. The proportion of times each candidate model returned the lowest AIC value as well as the greatest R^2 statistics when fitted to each subset was also recorded. Calculation of these proportions determine the relative frequency that any candidate model is found to have the best fitting (Anderson and Burnham [2002]).

The coefficient of determination, or R^2, is the proportion of the variance in the dependent variable that is predicted from the independent variables (or the proportional improvement in prediction from the regression model, compared to the mean model) (Dohoo et al. [2009]). It indicates the goodness-of-fit of the model. However, it directly but artificially increases as predictors are added to the regression model without representing an effective improvement of the model fit (overfitting). The adjusted R^2 accounts for this pattern, taking into consideration the model's degrees of freedom. It interprets the proportion of the total variance that is explained by only the independent variables that actually affect the dependent variable. Therefore, the adjusted R^2, as the AIC, they both penalize for the number of independent variables in the model.

For each candidate model, variables were considered significantly associated with live cattle prices Y_{ij} if the p-value of the Student t-test (for linear variables) or the p-value of the Fisher F-test (for non-linear variables) is less than 0.01. The proportion at which variables were found significant at an α level of less than 0.01 provides a measure of support for their association, which due to the use of bootstrap resampling is robust to the effects of sampling error in the original data.

The AIC and adjusted R^2 of each model over the 50 iterations were computed to assess the model with the best trade-off among these measures. The p-values of each explanatory variable within the model were also calculated to evaluate the significance of each variable ($alpha = 0.01$) over all the iterations. Both AIC and adjusted R^2 values were compared for all the proposed models over the 50 iterations, and the Δ AIC was then extracted for each tested model, as the difference between the AIC of each specific model and the highets AIC value among the tested models.

Among all the tested models (Appendix B, Table B.1) the final selected model consisted of:

$$\begin{aligned} Pi = \beta_0 + \beta_1 age + \beta_2 sex + \beta_3 in - degree + \beta_4 human\, density + \\ \beta_5 regional\, division + S_1(bovine\, density) + S_2(week) + \\ Z_1 market \end{aligned} \tag{6.3}$$

Where:

The dependent variable (Pi) is the observed price per individual animal traded treated as continuous variable and:

β_o the intercept

$\beta_1 ... \beta_5$ the coefficients allowed to vary across age, sex, market centrality, human density, and administrative district

S_1 the smoothing parameter for the cattle density

S_2 the smoothing parameter over the week variable

Z_1 the matrix of the random effect of the markets

Once the final model was selected, in order to measure the stability of this selected model and its resilience against data collection another 50 iterations of this final model fitting were carried out. The reference levels for all of the categorical k predictors (age, sex, human population density and administrative district) were female animals below 2 years of age sold in a market located in an area with an medium human population density (50-200 per km^2) within the Vina Division of the Adamawa Region.

The modeling was conducted using the *gamm4* package in R (R Core Team [2013]).

6.2.5 Model validation

The size of the dataset offered the opportunity to assess the variability of the model fit, and to increase the confidence of its robustness and its predictive performance. As such, the dataset was split into two subsets: a testing set and a validation set (Pinheiro and M. [2000]). By partitioning a dataset into two subsets, a training (or calibration) subset for model fitting and a test (or validation) subset for model evaluation, this cross-validation approach enables to test the predictive ability of the model (Pinheiro and M. [2000]). The idea behind cross-validation is to recycle data by switching the roles of training and test subsets when the sample is large enough to allow this procedure. The testing set was used to model the data and select the final model, whereas the validation set enabled us to evaluate the predictive performance of the model. For the purpose of this study, the validation set was composed of 10% of the entire data (n=11,800) using a stratified random sampling method. This sampling method was used to ensure that a representative fraction for each cattle type was present.

The predictive performance of the final model was assessed by comparing how well the predicted data fit the observed one using a combination of three measures comparing live cattle prices from the validation subset with predictions from the final model. These measures were the adjusted R^2, the mean absolute error (MAE) and the coefficient of variation (CV). The CV and adjusted R^2 are both unit-less measures that are indicative of model fit. CV and adjusted R^2 are both unit-less measures that are indicative of model fit, but they define model fit in two different ways: CV evaluates the relative closeness of the predictions to the actual values while adjusted R^2 evaluates how much of the variability in the actual values is explained by the model. The greater the adjusted R^2, the greater is the variance in the dependent variable explained by the model. By comparison, the lower the CV, the smaller the residuals relative to the predicted value, the closer the predicted values are to the actual values and, therefore, the better the model fit. Differently, the MAE measures the selection bias contributing to make the model inaccurate. By determining if the model has a positive or negative bias it's possible to assess if the model is underestimating or overestimating the observed values ([Chai and Draxler, 2014]).

All these measures (MAE, CV and Adjusted R^2) were used in combination to assess the ability of the model in predicting price of live cattle and, ultimately, to formally validate model performance.

6.3 Results

6.3.1 Descriptive results

Price variation and temporal effect

Starting from the first week of September 2013, the mean price per cattle traded throughout the following 12 months in the markets included in the study varied from a maximum of 263,000 CFA in week 17, coinciding with the week before the festivities for the end of the year, and a minimum of 211,000 CFA in week 26, in March almost at the end of the dry season (Figure 6.3).

Overall mean price per animal showed a fluctuation decreasing during the weeks of the dry season (Figure 6.3). Importantly, price of live cattle did not display any within year cycle, such as monthly or quarterly cycle, showing instead a pattern close to a yearly cycle returning approximately to the mean price of the previous year. However, as only a 12 month period of data observation was available it is not possible to make definitive conclusions.

Autocorrelation analysis was used to assess how price was related to itself over time. Figure 6.4 shows a correlation structure that fades between subsequent weeks as we take longer lagged values, notably after ten week lags. Partial au-

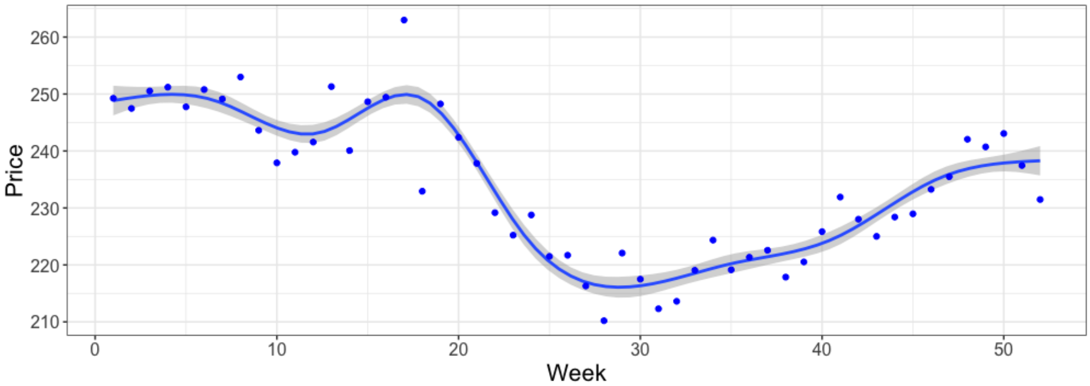

Figure 6.3: **Mean price over 52 weeks from the 1st September 2013 to the 31st August 2014.**
Mean price per animal (CFA x 1,000): the blue dots represent the mean price per animal in that week, the blue line the trend over the 52 weeks time and the grey shade the smoothing terms of the linear relation between the two variables.

tocorrelation, conversely, measures the strength of the autocorrelation between data at subsequent time points, but accounting for the correlation explained by the whole period of observations (control for the correlation due to the other week lags). The majority of the partial-autocorrelation (lag effect) are accounted for within week-by-week autocorrelation levels up to 2 weeks (Figure 6.4). After this two weeks period, the lag effect is negligible, therefore, not having a major impact on the price over time.

6.3.2 Model selection and cross-validation

Bootstrapping approach applying 50 iteration enabled comparison of performances of the 24 tested models including different meaningful combinations of the 9 predictor variables. Figure 6.5A displays the performance of the models measured by their adjusted R^2 and Δ AIC.

The models that showed the best trade-off between Adjusted R^2 and Δ AIC are the ones in the top-left corner of Figure 6.5A. Models were numbered so that

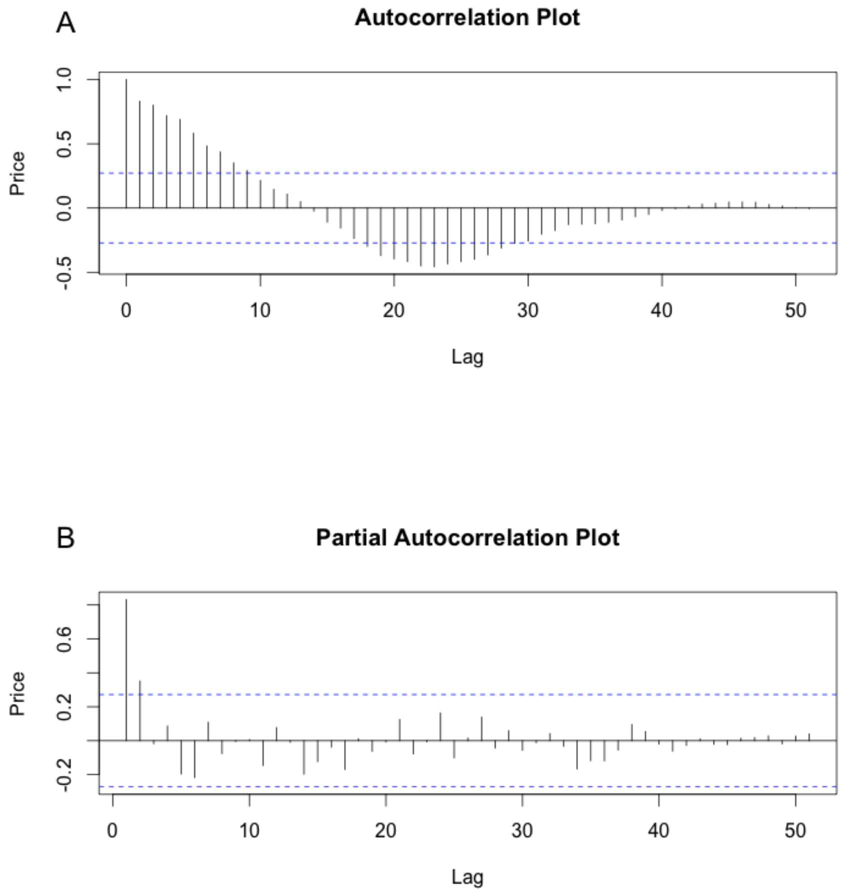

Figure 6.4: **Autocorrelation and partial autocorrelation for the mean cattle price over the 52 weeks of the year.**
A: Autocorrelation plot is showing a relationship between subsequent price observations recorded at weakly interval influencing up to 10 subsequent observations (blue line represents the 95% confidence band).
B: Partial autocorrelation plot is showing that only partial autocorrelations of the first and second lag are significant (blue line represents the 95% confidence band).

any odd number and the subsequent even number are equivalent models differing only for the presence, in the odd numbered model, or the absence, in the even numbered model, of the market centrality variable (*in-degree*) (Figure 6.5A). For instance, model 2 is equivalent to model 1 with the exception of lacking the market centrality variable (*in-degree*), and the same for model 6 compared to model 5 and so on.

Model 1, 5, 15 and 17 were selected for further assessment in order to identify the best fitting model. Models 5, 15 and 17 had a lower range of variability of the relationship between price and the temporal effect over the 52 week time window compared to model 1 (Appendix B, Figure B1). The variability over the cattle population density, when included as an independent variable (models 1, 5 and 15), was consistent between the subset models (Appendix B, Figure B2).

The distribution of the standardized residuals of the *fixed effects* of the models indicated a normal distribution of the residuals, with some skewness at extreme values for all these 4 models (Appendix B, Figure B3). By the contrary, the distribution of the *random effect* for model 5 had a slightly closer distribution to the normality assumption compared to the other 3 models (Appendix B, Figure B3). To further assess the fit of the model and the predictive ability of these 4 models and reduce the selection bias a formal cross-validation was carried out. The results from the cross-validation showed that models 1 and 5 had the lowest values of MAE and CV, and simultaneously the highest adjusted R^2 having the best fitting model (Appendix B, Figure B4). Considering the results from the model selection process and from the cross-validation stage and, importantly, considering the trade-off between adjusted R^2 and Δ AIC and the model parsimony, model 5 was identified as having the best fit and, therefore, selected as the final model.

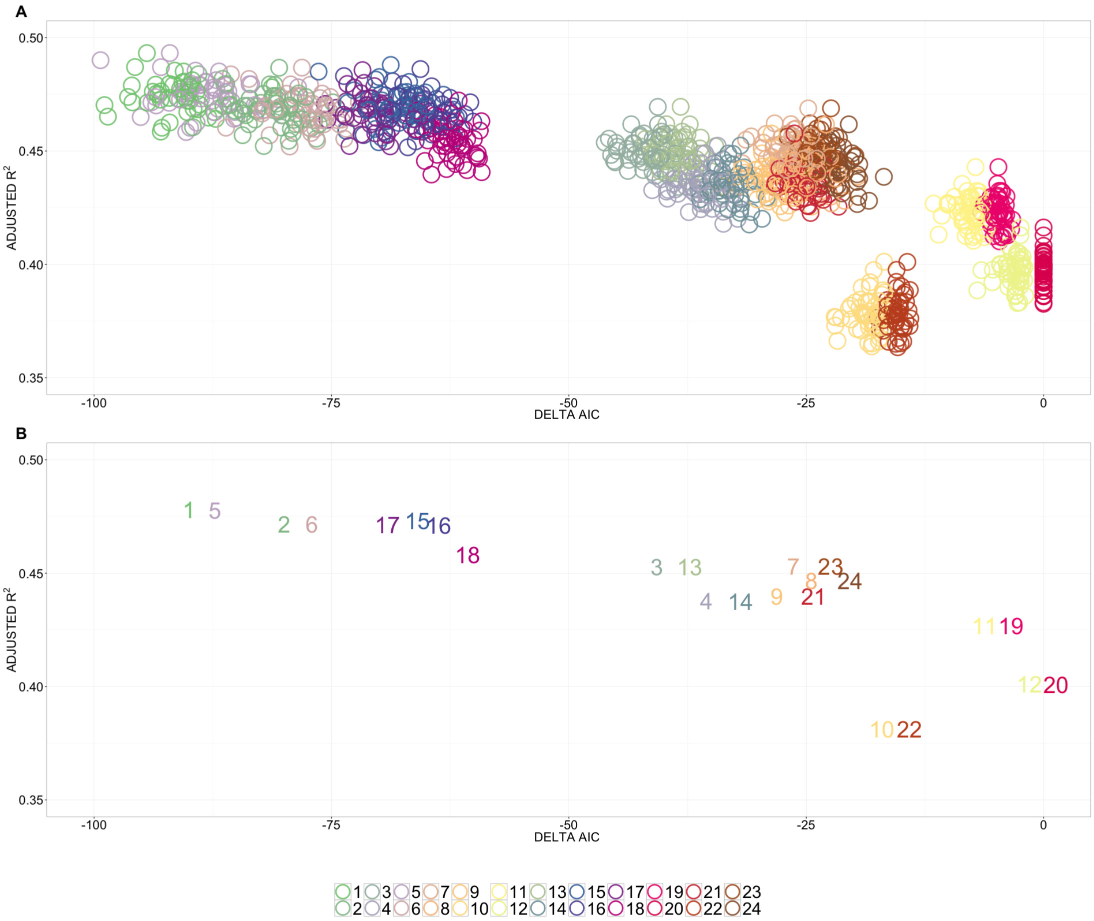

Figure 6.5: **Model selection over the 50 iterations.**
A total of 24 alternative models were assessed. The vertical axis reports the adjusted R^2 and the horizontal axis the Δ AIC values.
Figure A is showing clouds referring to 50 bootstrap iteration for each model. Figure B, instead, is displaying the mean values of Δ AIC and adjusted R^2 for each model.

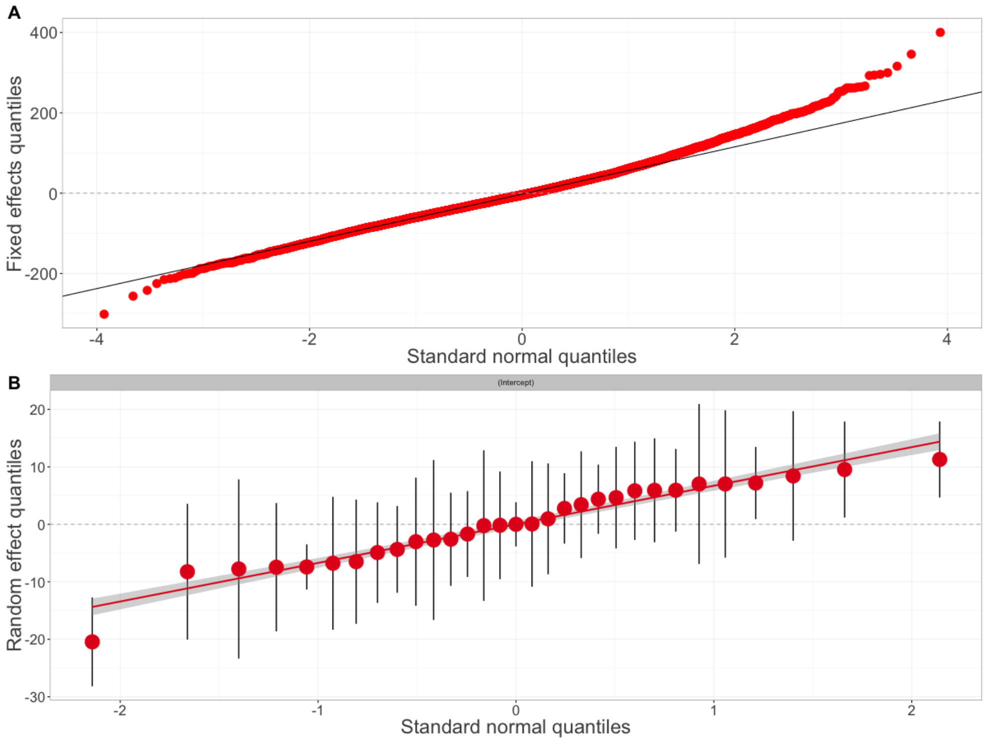

Figure 6.6: **Quantile-quantile plots for the *fixed* and *random effects* of the final model.**
Figure A: Distributions of the residuals errors for the *fixed effects* included in the final model. Figure B: Distributions of the residuals for the *random effect* (cattle market).

6.3.3 Final model results

A new set of 50 bootstrap iterations of the model fitting over the final selected model enabled to measure the variance of the adjusted R^2 and Δ AIC as well as the variance of the predictor variables. The normal distribution of the standardized residuals of the *fixed effects* and of the *random effect* of the final model are shown Figure 6.6. The statistical outputs of the final model including the mean and the ranges of the point estimates across the 50 simulation are shown in Table 6.2 and Figures 6.7 and 6.8. Table 6.2 shows the statistical outputs of the final model including the mean and the ranges of the point estimates across the 50 simulations.

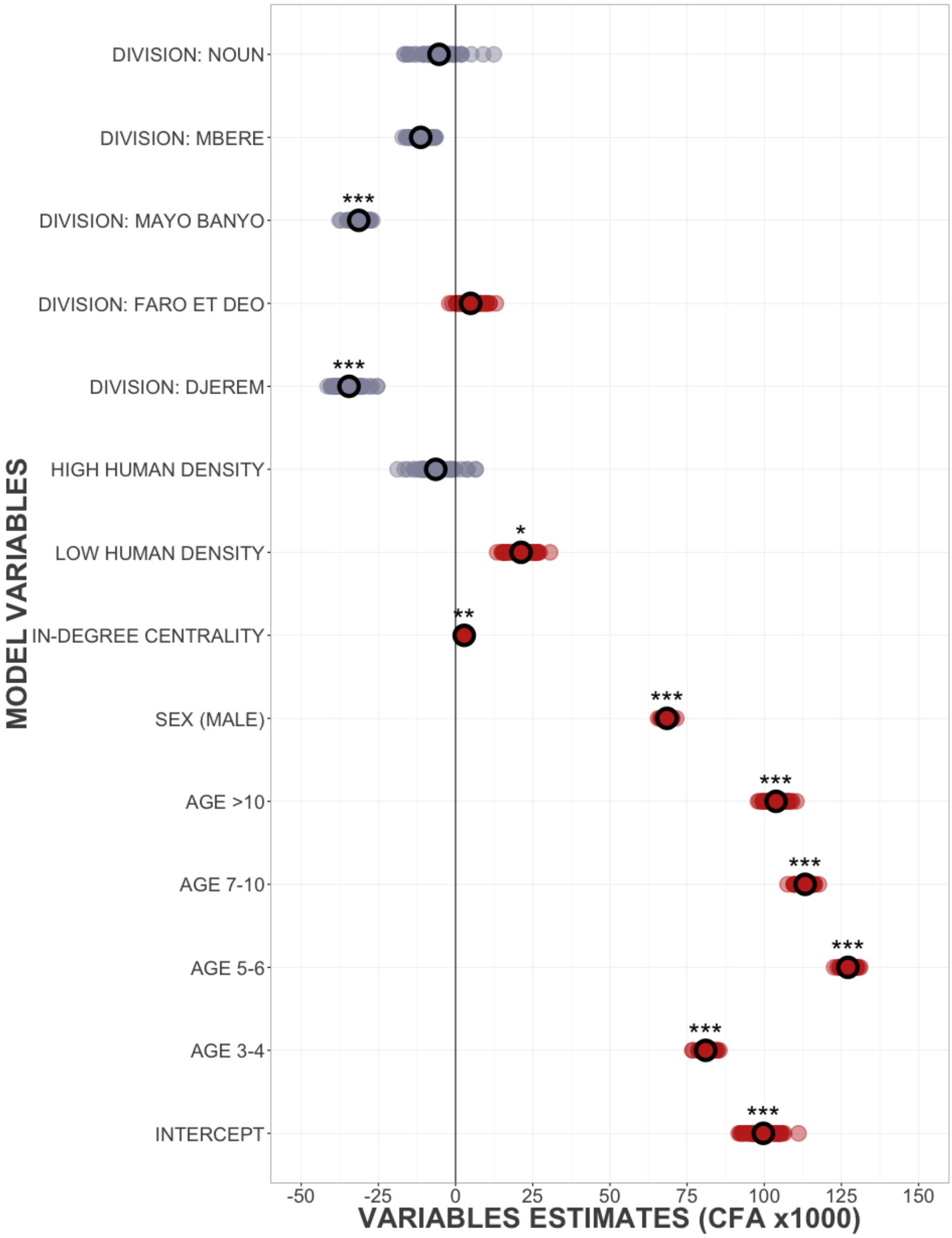

Figure 6.7: **Plot of the scale of the estimated *fixed effects* over 50 bootstrapping iterations.**

Inferred values for the predictive variables included in the model. Red dots relate to variables with a positive impact on mean price of live cattle, while grey dots relate to markets with a negative impact on mean price of live cattle. The black circle indicates the mean output over the 50 iterations. The chosen level of significance was p<0.01 and the stars refer to percentage occurrence of this level of significance in the 50 iterations (* >= 64%; ** >= 96%; *** = 100%).

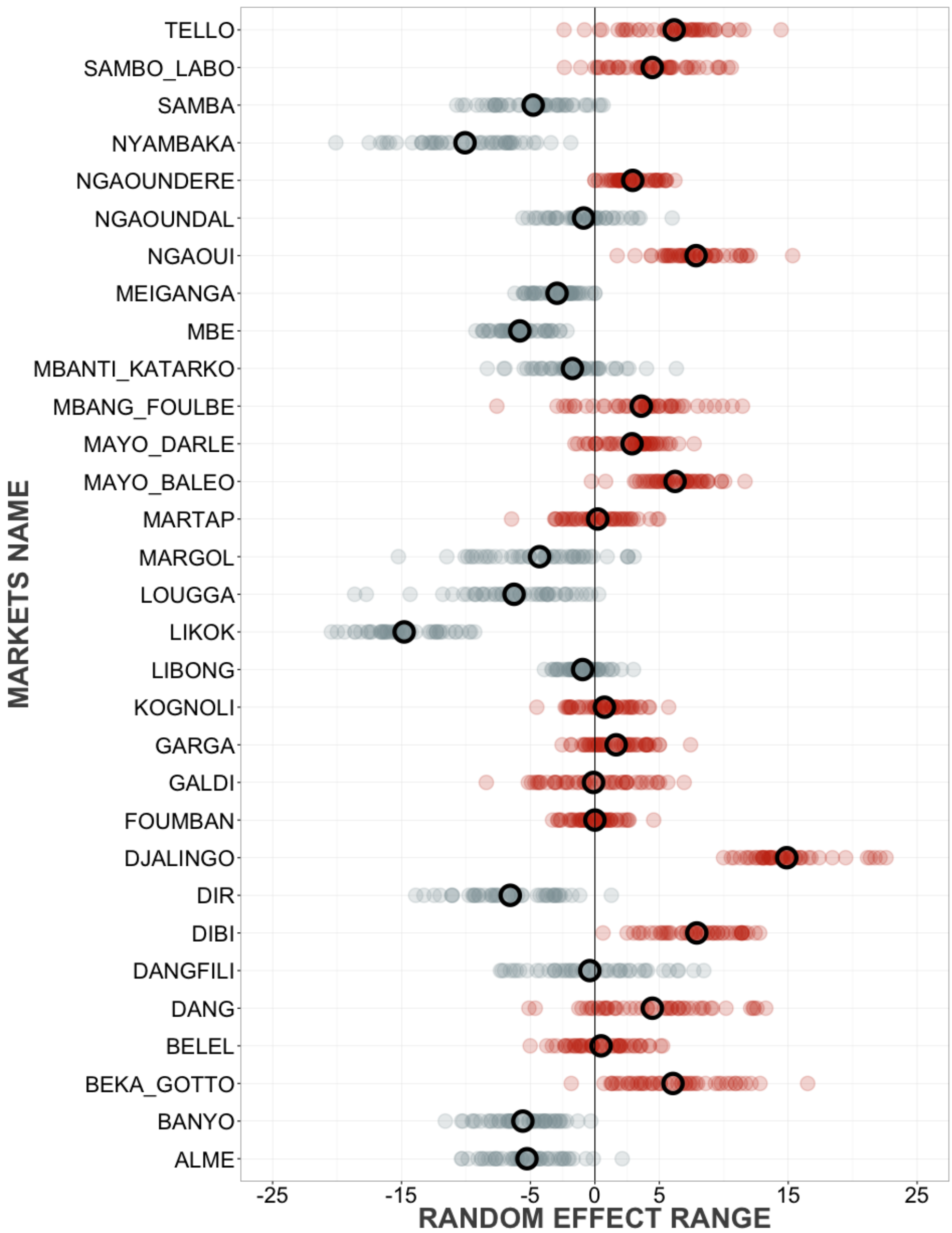

Figure 6.8: **Plot of the *random effect* estimates for each market.** Inferred values for each of the 31 markets included in the study. Red dots relate to markets with a mean positive association on price of live cattle, while grey dots relate to markets with a mean negative association on mean price of live cattle. The black circle indicates the mean output over the 50 iterations.

Table 6.2: Final model (5) outputs over 50 bootstrap iterations and relative accuracy and variability. Model point estimates, standard errors and significance. In brackets the range of the point estimates and the 95%CI of the standard error. The proportion of significance is given by the significance through the 50 bootstrap iterations (level of significance p <0.01).

	Estimates	*Standard Errors*	*Proportion of Significance*
Intercept	99.960	7.702	100%
	(91.45, 108.8)	(7.65, 7.74)	
Age 0-2	Reference		
Age 3-4	81.226	1.588	100%
	(78.1, 85.8)	(1.587, 1.589)	
Age 5-6	127.298	1.707	100%
	(122.3, 130.3)	(1.706, 1.708)	
Age 7-10	113.430	1.972	100%
	(107.7, 117.1)	(1.971, 1.974)	
Age >10	104.217	2.918	100%
	(98.6, 111.4)	(2.914, 2.922)	
Sex Female	Reference		
Sex Male	68.460	1.237	100%
	(65.5, 71.4)	(1.236, 1.238)	
Medium Human density	Reference		
Low Human density	20.930	7.410	64%
	(14.1, 28.4)	(7.364, 7.457)	
High Human density	−6.598	12.266	0%
	(-17.2, 6.4)	(12.180, 12.1353)	

Network In-degree	2.805	0.771	96%
	(2.1, 3.6)	(0.766, 0.776)	
Division: Vina	Reference		
Division: Djerem	−34.519	6.823	100%
	(-40.9, -26.4)	(6.782, 6.864)	
Division: Faro et Deo	4.001	10.327	0%
	(-3.1, 12.1)	(10.257, 10.398)	
Division: Mayo Banyo	−31.510	6.205	100%
	(-36.1, -28.1)	(6.162, 6.247)	
Division: Mbere	−11.577	7.694	0%
	(-17.1, -4.5)	(7.644, 7.744)	
Division: Noun	−5.795	14.363	0%
	(-17.9, 9.5)	(14.469, 14.258)	
Akaike Inf. Crit.		132,654	
		(132,194-133,160)	
Adj R^2		0.474	
		(0.456-0.489)	

Cattle age and sex had a significant effect on cattle price (100% of bootstrapping simulation was significant at $p < 0.01$), with male animals being about 68,000 CFA more expensive than female cattle (Figure 6.7). The association with animal age showed to increase with age, having a higher impact on the price for animals between 5 and 6 years of age, and then decreasing with animals getting older. Human population density was also associated with cattle price, notably with price being significantly higher in areas with a lower population density compared to areas with a medium human density. This association was found significant with $p < 0.01$ in 64% of the bootstrapping simulations with an mean impact value of 20,900 CFA (range 14,100-28,400). Conversely, despite few exceptions out of the 50 iterations, cattle tended to be traded at a lower price in areas with a high human density. However, this association was not considered statistically significant (0% of bootstrapping simulation was significant at $p < 0.01$) (Figure 6.7).

The centrality of the market within the cattle trading system was directly related to price, and price was increasing in markets with higher *in-degree* centrality. This association was significant in 96% of the simulations ($p < 0.01$) with a mean positive impact value of 2,800 CFA (range 2,100-3,600) per unit of *in-degree*, therefore per in-coming connection (Figure 6.7).

The shape of the functional form for the selected covariates with a non-linear relation to cattle price are shown in Figure 6.9. The shape of the smoothed term for the 52 weeks period was consistent across the 50 iterations, displaying only some limited variability in 2 bootstrap iterations, and showing an overall variation of price of about 20,000 CFA across the year (Figure 6.9A). In particular, the highest peak was between week 5 and week 7, and the lowest peak between week 30 and week 40.

Similarly, the shapes of the smoothed terms for the cattle density consistently showed an increasing relationship with cattle price from lower to medium bovine population densities across the 50 iterations (Figure 6.9B). This curve reached a maximum between 20 and 25 cattle per Km^2, beginning to slowly decrease when cattle population further increased. Overall, cattle price had a variation range of about 40,000 CFA across the areas with different cattle population densities. Markets located in areas with the lowest cattle densities ($<15Km^2$) tended to be about 40,000 CFA less expensive than cattle traded in markets located in areas with the highest cattle density in the study area (>20 - $<30Km^2$) (Figure 6.9B).

When looking at the administrative districts where animals were traded, Djerem and Mayo Banyo Divisions in the Adamawa Region were always significantly associated with a mean reduction in price of about 25,000 CFA compared to the Vina Division of the same Region (100% of bootstrapping simulation was significant at $p < 0.01$). Other Divisions did not show any significant impact on the price of traded cattle (Figure 6.8).

Including the livestock market as a *random effect* allowed to account for the variability in cattle value between markets, estimating the effect of specific markets on the price of traded cattle (Figure 6.8). Figure 6.8 highlights that relative few markets (n=7) are not overlapping the random zero effect across the 50 iterations, therefore having a consistent significant impact over the 50 iterations. Three markets, all located in the Vina Division of the Adamawa Region, have a consistent positive effect on cattle price (Dibi, Djalingo and Ngaoui). By the contrary, 4 markets, 3 in the Vina and 1 in Mayo Banyo Divisions of the Adamawa Region, have a consistent negative effect on cattle price (Nyambaka, Likok, Mbe and Banyo). The location and the relative mean estimated effect over the price

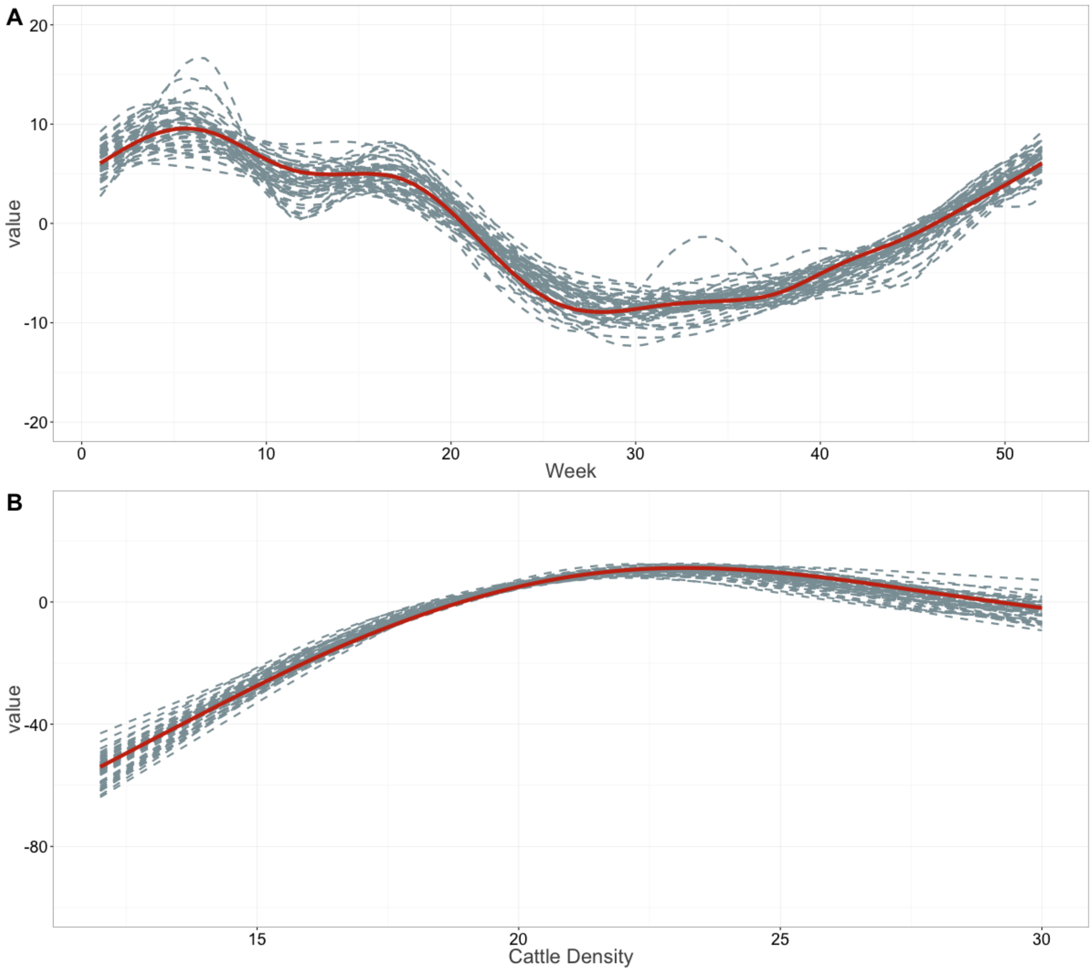

Figure 6.9: **Smoothed fits of covariates.**
Smoothed fits of covariates modelling A) the temporal relation with cattle price and B) the bovine population density. Tick marks on the x-axis are observed datapoints, and the y-axis represent the spline function. Grey dashed line indicate the smoothed fits for all the 50 iterations; the red solid line the mean smoothed fit.

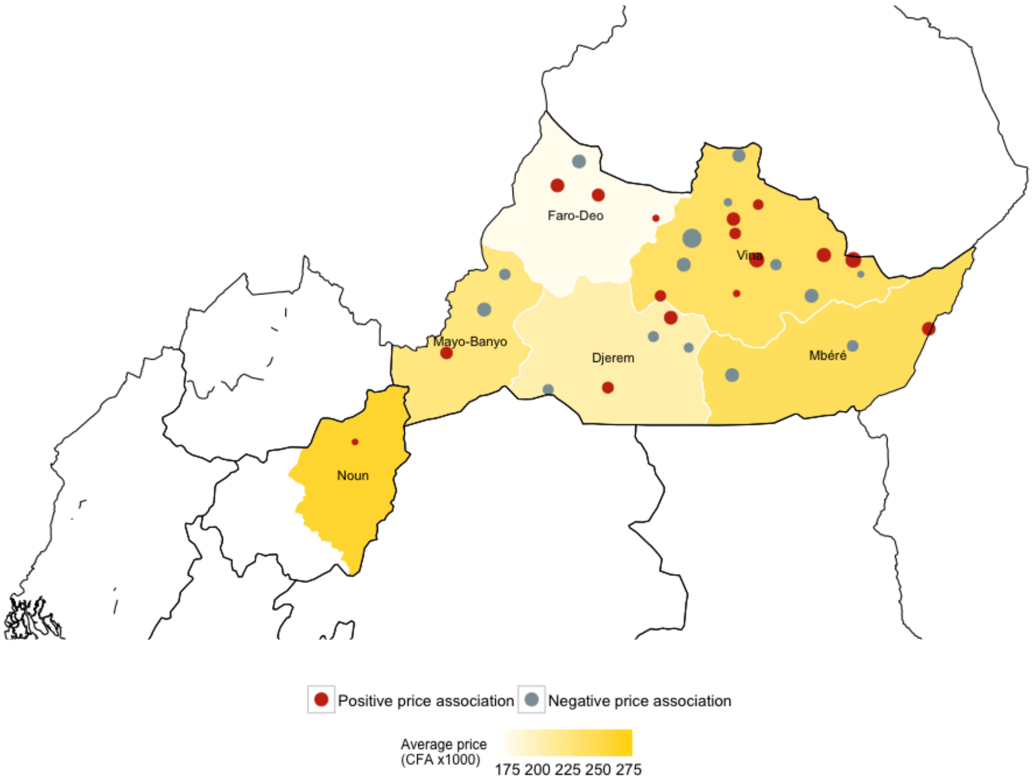

Figure 6.10: **Geographical distribution of the markets and their estimated effect on the price of the traded cattle across the study area.**

Red dots relate to markets with a positive association on mean price of live cattle, while grey dots relate to markets which a negative association on mean price of live cattle. The size of the dots is proportional to the entity of the impact on price: the bigger the dot the bigger the effect on the price. The intensity of the yellow colour, instead, relates to the mean price of animals traded in each Division within the study area.

of traded cattle for each market are shown in Figure 6.10. Both the market with the biggest positive (Djalingo) and the one with largest negative (Likok) effects were located within the Vina Division of the Adamawa Region.

6.3.4 Impact of market centrality on price of traded cattle

To further assess the effect of market centrality on cattle price all the models considered for the selection process were also assessed in duplicate, so that models including *in-degree* as a measure of market centrality could be compared with equivalent models without this measure of network centrality. Figure 6.11 shows a consistent pattern across all the tested models. In the models including market *in-degree* centrality as a predictor both the adjusted R^2 and the Δ AIC were improved (higher adjusted R^2 and lower Δ AIC) across all the 50 iterations, in comparison to equivalent models not including *in-degree* centrality.

The overall consistency of these results across the 50 iterations (Figure 6.11) and the significant association ($p<0.01$) of *in-degree* centrality with cattle price in 96% of the simulations (Figure 6.8) highlights a direct relation between the connectedness of the market within the trading system and the price of cattle traded at that market.

6.3.5 Predictive ability of the model

The cross-validation of the final model showed that the CV of the model was equal to 27.7. The adjusted R^2 explained the 47.4% of the variability in the price. The absolute measure of the variance, given by the value of the MAE was 49.6, therefore, the mean disagreement between the predicted and the observed cattle price was 49,600 CFA, equivalent to about the 20% of the mean cattle

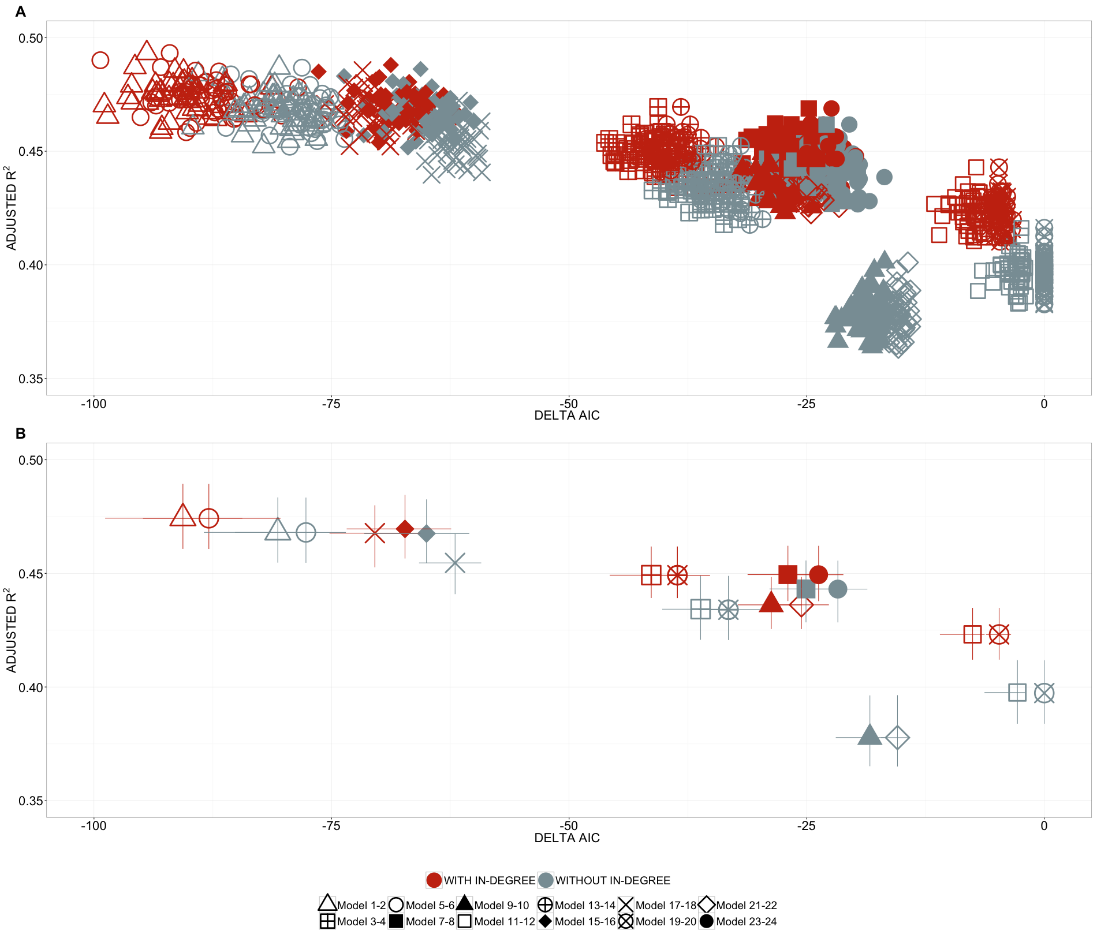

Figure 6.11: **Effect of market centrality on models performance.** The red colour refers to models including in-degree centrality as a predictors while grey colour to models both including it. The shapes of the points refer to equivalent models, only differing by the inclusion or exclusion of in-degree centrality among the predictors(e.g. the red square shape is equivalent to the grey square shape). The vertical axis reports the adjusted R^2 and the horizontal axis the Δ AIC values.
Figure A is showing clouds referring to 50 iteration for each model.
Figure B, instead, is displaying the mean values of Δ AIC and adjusted R^2 for each model, with the bars representing the ranges of variation across the 50 iterations.

price across the study area (Figure 6.12). Figure 6.12 shows that the predictive ability of the model varied between cattle types. The price of bulls and steers was generally overestimated as well as the one of heifers, while the model tended to underestimate the price of cows and young bulls. The median actual difference between observed and predicted price for bulls was 26.8 CFA (quantile range -13.2 to 78.0), for steers 50.6 CFA (quantile range -14.2 to 105.2) and 25.1 CFA for heifers (quantile range -8.0 to 53.6), while for cows was -13.9 CFA (quantile range -43.6 to 17.9) and -32.9 CFA (quantile range -64.3 to -2.1) for young bulls (Figure 6.12).

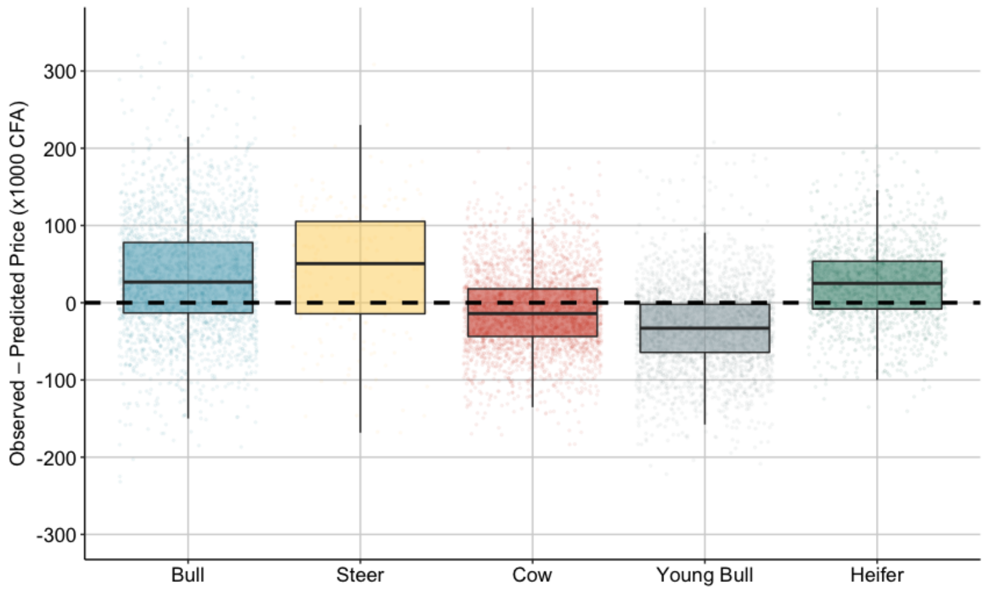

Figure 6.12: **Predictive ability of the model.**
Visualization of cross-validation output. Observed prices of live cattle at the market level are displayed on the x axis and fitted values on the y axis (prices are in CFA x1000). In the top left of the figure are displayed the values of the adjusted R^2, MAE and the CV. The dotted black line represents the 1:1 identity line.

6.4 Discussion

In Cameroon the livestock sector contributes 20% of the agricultural GDP and, as in most of SSA, livestock production is an essential resource for households in the rural areas (Pamo [2008]). Livestock are a crucial asset for mitigating the vulnerability of rural households to a number of external factors, such as climate change, animal diseases and social and political instability (Todaro and Smith [2014]), and sale of livestock is a key mechanism for rapid cash generation (Little et al. [2001]). Livestock value, therefore, besides being an important source of revenue for the local and national public sector, has a central impact on the welfare of most rural households as well as on family expenditure in urban households (Todaro and Smith [2014]).

The aim of this Chapter was to study the factors that determine the formation of live cattle price at livestock markets within the major pastoral and livestock production areas of central Cameroon. Official documentation from 31 livestock markets out of a total of 37 markets in the study area provided records of prices of the traded cattle for the period between September 2013 and August 2014, hence, enabling empirical investigation of cattle price formation within the livestock trading system.

In this study, as expected from observations during the data collection and from the characterization of the cattle trading system carried out in Chapter 4, age and sex showed to be important factors affecting the price of live cattle. An higher price was directly associated with adult animals and particularly males (bulls or steers). Similarly to the current results, also in semi-extensive and intensive production systems, the value of these cattle types has been related to the live animal weight at sale (Christofari et al. [2010]; Koetz Júnior et al. [2014]) and to cattle breed (Barham and Troxel [2007]; Troxel and Barham [2007]; Koetz

Júnior et al. [2014]). In the current study the Goudali cattle breed, considered to be a higher value animal in Cameroon, is specifically bred in the Vina Division of the Adamawa Region (Pamo [2008]). In pastoral contexts cattle breeds are also considered as a cultural property playing a central part in the agriculture tenures and in the social life of rural populations (Gandini and Villa [2003]). In this study the generally significant negative impact on price of trading outside the Vina Division might also relate to the fact that this is the only Division where the Goudali cattle breed can be officially traded. However, the information both on live animal weight and cattle breed is currently not recorded at the livestock markets in Cameroon and, therefore, could not be included in the current analysis.

Although information about the breed of traded cattle could be relatively easily collected at the market level, in the Cameroonian context the opportunity to gain information on the weight of traded animals is currently more challenging, *in primis* due to infrastructural limitations at the market level. Nevertheless, alternative approaches such as body condition scores and methods to assess body weight could, therefore, represent applicable and relatively not time consuming options to be routinely implemented at the market level to reduce this information gap.

Adult cattle, and particularly bulls and steers, are usually considered the most suitable for human consumption in various contexts (Christofari et al. [2010]; Koetz Júnior et al. [2014]) and it is believed that cattle are sold at higher prices in markets located in areas of high human densities, as in urban centres (Williams et al. [2006]). In contrast, in this study we found that cattle tended to be traded at lower prices in markets located in areas with a higher human density. It is important to consider that the Adamawa Region, where the vast majority of these markets were located, is mainly a pastoral highland very sparsely populated and with a limited number of urban centres (MINEPIA [2014]). The characteristics of the study area, therefore, might limit the generalisations of this specific result to the whole country, particularly to Regions with greater human densities and a higher number of urban centres such as in southern Cameroon.

Within the current study area smaller markets are located in zones with higher cattle densities and lower human densities while the opposite is true for bigger markets, which are generally in areas of higher human population density. While the objective of including the distribution of human and cattle populations in the analysis was also to account for their impact on local demand and supply on cattle price, it is likely that a more formal and specific estimation of the demand and supply at the market level would help assess more accurately their impact on livestock price formation. More generally, including markets located in high consumption Regions in southern Cameroon, could have provided also a more global understanding at a national level of human and cattle populations as determinants of live cattle prices. However, this analysis was limited by the unavailability of data on price of individual live cattle from the official records of markets located in those areas of the country.

The overall restricted range of price variation among markets, additionally, shows the absence of evident price differentials between markets within the current study area. On the contrary, the available information from the other markets, where official documentation was collected but not available for individual animals, showed a more evident price differential between production zones, such as the Adamawa and the West Regions, and consumption zones in the southern Regions of the country (Section 4.4 of this thesis). Generally, prices of related goods at different locations, within a given area, that are following similar patterns, or moving proportionally, are known to provide a certain level of protection against the shocks of the broader trading system (national or international) (Barrett and Li [2002]; Serem et al. [2007]). The level of market integration between local, national and international markets is a key information, particularly in developing countries, for assessing the impact of price shocks into local economies and to what extent are these transmitted to domestic prices (Serem et al. [2007]; Baquedano and Liefert [2014]). The current findings, hence, support the need for better understanding how prices in the cattle trading system in Central Cameroon relates to the wider cattle trading system in the country and the region, and for assessing the potential impacts on the local cattle market in these pastoral areas of external market shocks that could eventually affect the local economy and the rural households.

Over the 12 month observation period in the specific study area for this chapter (31 markets in the Adamawa and West Regions) cattle trading value was not heavily affected by the period of the year. This might suggest that in the current context there might be lacking major incentives, or key inputs, for investing in cattle production across seasons, for instance in fattening animals during the rainy season to supply the market during the dry season, when, generally, animal conditions tend to be affected by the challenging environmental conditions. Importantly, we need to consider again the specific rural and pastoral context where this study was carried out and the limitations in extending this reasoning to the overall country. As discussed in Chapter 4, in fact, within the wider cattle trading system including also the North-West Region and the major markets in southern Cameroon, generally, there is a reduction in the volume of cattle on the market during the dry season, which is also accompanied by an opposite trend in the cattle price. This pattern was more evident in the markets located in the high demand urban centres of Yaoundé and Douala, and only to a minor extent in the cattle production areas of the North-West and Adamawa Regions.

The reason for trading cattle (e.g. breeding, slaughter, re-sell) would represent another important factor for refining the study of live cattle price determination. Similarly, moving cattle for long distances is known to contribute in adding additional transaction costs, either if the transportation is made on foot or by vehicle (Onono et al. [2015]). In particular, transportation by vehicles can account up to 70% of the transaction costs in the livestock trading system in SSA (Barrett et al. [2003]). Therefore, the distance travelled and the means of transportation might represent an additional relevant factor for price determination which could not be captured in the present study.

Highly connected markets within the livestock trading system of Cameroon tended to contribute to an increase in the price of live traded cattle. Although, we cannot exclude that this relation between cattle price and connectedness of a market, and more specifically with *in-degree* centrality (the number of incoming connections to that specific market) could potentially represent a proxy for other underlying factors influencing price (such as the number of traders and herders attending the markets or the supply of live animals at the market) this may suggest a potential relation with the dissemination of infectious diseases within the cattle trade system. Markets with a higher number of incoming connections are exposed to a higher number of possible sources of diseased animals (Christley et al. [2005]; Dean et al. [2013]; Gates and Woolhouse [2015]; Sintayehu et al. [2017]), and this finding highlights a potential relationship between a central driver of disease dynamics, such as livestock movements, and a key economic factor for cattle trade, such as live animal market value. The higher price of cattle at highly connected markets could increase the risk of disease spreading by incentivizing movements of animals to these markets, highlighting how network analysis increasingly represent a useful tool to be included also in epidemiological strategies for disease control (Moslonka-Lefebvre et al. [2016]).

This study could not include data about phenotypic traits, such as the cattle breeds and the weights of the traded animals, as well as information about the reasons for trading or transaction costs, as currently they are not collected during the transactions carried out at the market level. Additionally, some of the official record providing the data on cattle price and on some of the predictors used in this study (e.g. age, sex, data and market of trade) were missing the information about the age of the traded animal. As missing data arising from nonresponse can lead to biased estimates if the analysis is restricted to the records with complete information this information was imputed using the other data available from the official records. Although, imputation may potentially distort distribution of the variables and alter associations between outcome and predictive variables the distributions were controlled in this study and the categorisation of age was defined in order to minimise this effect. Generally, this type of information, including phenotypic traits of the traded animals, is either missing or not consistently recorded and should be routinely registered across the country to inform pricing procedures and policies to improve the livestock marketing system. In particular, objective animals weight measurements (scales/estimation) would increase accuracy of price formation, reducing room for traders' speculations and increasing protection in negotiations for herdsmen and their households, particularly in the pastoral areas of Cameroon.

In the current study, the size of the available dataset enabled to apply an iterative modeling approach to assess the variability of the model and increase the confidence in the robustness of the inferences that could be drawn from these results consistently explaining about 50% of price formation across the iterative modeling approach (Austin [2008]). Although the available data did not allow to include information about phenotypic traits, such as the cattle breeds and the weights of the traded animals, as well as information about the reasons for trading or transaction costs, this model consistently explained about 50% of price formation across the iterative modeling approach.

Finally, this study potentially provides important information for more evidence-based strategies for disease management. Previous studies have shown that epidemiological strategies alone are not always the most economically viable and that sound cost-benefit analysis are increasingly required for better assessment of their feasibility and effectiveness (Moslonka-Lefebvre et al. [2016]). The outputs of this study would ideally contribute to the estimation of the impact of infectious diseases, in terms of direct and indirect losses (Knight-Jones and Rushton [2013]), as well as to the evaluation of animal health control interventions in production areas of SSA. In particular, the key factors affecting cattle price should help developing a more objective price information system for improving livestock marketing and, importantly, should be accounted for in the estimation of the economic impacts of epidemiological strategies for disease management (e.g. risk-based interventions and compensation schemes).

6.5 Conclusion

The heterogeneity of the factors contributing to live cattle price formation in the pastoral context of Central Cameroon is showing the complexity of generalising these results to the broader country. While some animal related factors are clearly contributing to price formation, the interaction between other determinants creates a complex framework highly context dependent.

The relatively small impact of markets in the study area over price of traded live cattle suggests the need for a more tailored study on the integration of the livestock marketing system, and its implications for the vulnerability and resiliency of the rural households to external shocks affecting livestock production and trade. The positive association between the centrality of the markets in the cattle trade network, and in particular between the incoming connections and the price of live cattle, also highlights a relation between drivers of disease transmission, such as cattle movements, and key economic factors such as animal value.

Improving and standardising the information recording system at the market level across the country, accounting for phenotypic data as well as transaction costs, would provide a more objective price formation at the market level, reducing the margins for speculations by the traders and increasing the protection for the cattle herders. Importantly, it will also enable a more thorough evaluation of the policies for the management of the livestock sector in the country, particularly for a more effective resource utilisation for the management of livestock health and production in the country.

Chapter 7

Cattle transhumance in the pastoral system of central Cameroon: a pilot study

7.1 Introduction

Livestock mobility is an important strategy and the principal means by which pastoralists cope with and take full advantage of natural resource variability in drylands (McGahey, D. [2002]). Pastoralist communities are characterised, historically and socially, by livestock rearing as their primary activity (Dyer et al. [2008]). Pastoralism represents a key adaptation for human and livestock populations to the variability of environmental and ecological resources (McGahey, D. [2002]; Scoones and Wolmer [2006]). The term transhumance is used to describe the seasonal movement of pastoralists to regions of different climate to take advantage of the seasonal availability of grazing for their livestock. In arid and semi-desert parts of the world transhumant movements are, usually, in response to seasonal rainfall patterns. Transhumance tends to be towards remoter riverine areas and as a result, peoples and livestock migrate through and spend most of the time in areas where there are rarely veterinary or medical facilities, as well as safe water supplies or sanitation (Scoones and Wolmer [2006]). Livestock movements can result in the dissemination of endemic diseases, or in the introduction and spread of exotic animal diseases (Fèvre et al. [2006]). In particular, transhumance movements in SSA increase the chances of coming into contact with geographically limited or seasonally abundant diseases, such as trypanosomiasis and multiple parasitic diseases (Macpherson [1995]). In SSA, both the movement and mixing of livestock at higher than usual densities and the contact with wildlife that occur during transhumance are risks factors for the dissemination of a number of diseases (Macpherson [1995]), including foot-and-mouth disease (FMD) (Bronsvoort et al. [2004b]).

In Cameroon, as across a number of other countries in SSA, transhumance is a common practice to cope with ecological and environmental constraints. In Cameroon transhumance occurs in the dry season (October to April) (Pamo [2008]). During this period a large proportion of cattle herds from the main livestock production areas of Cameroon move in search of water and fresher pastures following diverse paths across the country. Previous studies in the Adamawa Region of Cameroon have reported that around 50% of the cattle herders undertake transhumance (Bronsvoort et al. [2003]; Kelly et al. [2016]) while in the current thesis about 25% of the interviewees at the livestock markets in this Region reported undertaking transhumance (Section 4.3.13 of this thesis). Transhumance patterns vary in terms of the distance covered, of the duration of stays in various locations as well as of the daily patterns of movements during these periods. In the Extreme-North, North-West and West Regions of the country most cattle herds are reported to undertake a more local migration largely remaining within the Region (Xiao et al. [2015]). In contrast, herds in the Adamawa Region are known to be more mobile, migrating more extensively including externally towards other Regions of origin and into neighbouring countries (Section 4.4 of this thesis). However, knowledge of these routes and trajectories are limited to anecdotal and informal reporting. Characterizing the seasonal transhumance trajectories and the nomadic herding practices is therefore a key information for better understanding the patterns of interactions within the livestock population and, hence, their implications for infectious diseases transmission and circulation.

The study of animal mobility, both of wild and domestic species, currently relies on three main approaches: direct observation, capture-recapture techniques and real-time tracking. Over the past decades natural scientists have used diverse real tracking methodologies to gather data on the location of an individual animal at a specific time and to understand the behavioural ecology of free ranging species. Currently, the most common methods for real-time tracking of animals use satellite or radio based locators. Global Satellite Navigation Systems (GNSS) is the generic term for satellite navigation systems that provide autonomous geopositioning with global coverage (Bonnor [2012]). The most widely used GNSS system to date in studying livestock movement is the global positioning system (GPS) (Handcock et al. [2009]). GNSS devices for tracking animals were firstly employed in 1997 and, between 1997 and 2013, a total of 99 studies were reviewed deploying these devices, including GPS-based systems, to monitor free-ranging cattle movements and behaviours (Anderson et al. [2013]).

Since 1997, several studies have investigated the movement behaviour of wildlife and livestock animals in Africa using global positioning system (GPS) technology (Handcock et al. [2009]; Anderson et al. [2013]) and, more recently, mobile phone systems (Jean-Richard et al. [2014]). Notably, GPS-tracking technology has been employed in SSA to study grazing behaviour of free-ranging cattle and their response to the spatio-temporal variability of vegetation resources (Schlecht et al. [2004]; Schlecht et al. [2006]; Butt et al. [2009]; Moritz et al. [2012]; Augustine and Derner [2013]; Raizman et al. [2013]; Feldt and Schlecht [2016]), to characterize the movements of nomadic pastoralist communities (Sonneveld et al. [2009]) and to collect data on the movements of both traders and traded herds (Tempia et al. [2010]). However, to date, the formal study of livestock transhumance is still limited in SSA and there are no reports of GPS tracking of transhumance routes or concomitant surveys of key practices and issues herders and livestock encounter during transhumance. Although GPS-tracking technology it is still a relatively expensive study methodology, investigating grazing behaviour of free-ranging cattle in East and West Africa showed that the trajectory of a single animal is representative of the daily grazing orbit and of the movement patterns of an entire herd (Butt et al. [2009]; Moritz et al. [2012]; Feldt and Schlecht [2016]). These findings, therefore, show that GPS-tracking technology provides a suitable framework to be applied for reducing the knowledge gap on the understanding of movements and practices during livestock transhumance.

Movements within and between populations are a central driver of livestock disease dynamics (Fèvre et al. [2006]) and empirical information, including precise seasonal cattle transhumance trajectories would help informing a more evidence-based approach to animal health management in Cameroon. In Cameroon, although transhumance has already been reported as a common practice for a relevant proportion of the cattle herders, particularly in the Adamawa Region (Bronsvoort et al. [2003]), little knowledge of the migratory routes and of the actual grazing locations is currently available. Information about the common practices during this seasonal migration is key for better understanding cattle movements as a whole, and for assessing the interactions between pastoral and trading systems in the country. Information about the common practices during this migration could also help identifying major risks and implications for the spread of infectious diseases in the country. Overall, acquiring empirical information about the seasonal cattle transhumance would help informing a more thorough discussion on animal health in the country, and to improve the design and planning of interventions for the development of animal health management.

7.2 Objectives

The overall aim of this chapter was to carry out a pilot study to explore the feasibility of applying GPS-tracking technology, particularly collar devices, to study cattle herds transhumance for the entire duration of the migration. Obtaining a general picture of this system, including key information of trajectories and animal management practices of the transhumant animals, would also provide valuable information to begin filling the knowledge gap regarding this common seasonal herd mobility.

In this chapter 10 cattle herds originally located in the Adamawa Region of Cameroon were tracked for a period of over six months and upon their return a questionnaire-based survey was used to collect information on herding and animal management practices during the migration.

The objectives of this pilot study are twofold. Firstly to characterise the seasonal transhumance routes of a restricted pool of cattle herds normally grazing in the Adamawa Region, including the estimation of their daily patterns of movements. Secondly, to collect information about the common management practices of these transhumant herds during the migration, their interaction with other herds and/or with wildlife and their relation with the trading system.

7.3 Materials and Methods

7.3.1 Study area and herd identification

At the beginning of the field work for this project, between October and November 2014, consultations with veterinary officials and with other markets stakeholders at various market locations in the Adamawa Region enabled us to identify cattle herds owners willing to participate in a pilot project for tracking cattle during the seasonal transhumance. Between October and November 2014 ten cattle herds were identified that were prepared to participate in the study. They were conveniently selected depending on their availability and included herds normally grazing in three different Divisions within the Adamawa Region (Table 7.1).

Cattle herds have been observed to synchronise their behaviour, to a large extent, to more socially dominant individuals, particularly during travelling and grazing activities (Rout et al. [2002]; Dumont et al. [2005]; Šárová et al. [2007]). In each herd, one animal was selected to carry the GPS device. Selection was first based on discussions with the herdsman to identify socially dominant animals within their herd. Each identified animals were then inspected clinically to ensure that they were robust and healthy. Details on the animals chosen to carry the GPS device in each selected herd are shown in Table 7.1.

7.3.2 Data collection approach (*G_1, G_2 and G_3*)

Lightweight (320g) GPS collars (Savannah Tracking Ltd., Kenya) (G_1 in Figure 3.3) with GSM network access and on-board backup data storage were fitted to each selected animal (Table 7.1) (for details see Section 3.5.2).

As herds are usually taken on transhumance and supervised by one or more

Table 7.1: **Cattle herds identified in the Adamawa Region of Cameroon.**

Collar num.	**Location**	**Division**	**GPS deployment**	**Herd size**	**Tracked animal**
1299	Likok	Vina	18/11/2014	45	cow (4y)
1300	Belel	Vina	25/10/2014	57	cow (4y)
1301	Nyambaka	Vina	24/10/2014	35	bull (4y)
1302	Likok	Vina	03/11/2014	40	bull (4y)
1303	Margol	Vina	03/11/2014	71	cow (5y)
1305	Dir	Mbere	05/11/2014	93	bull (4y)
1306	Lougga	Vina	19/11/2014	52	cow (6y)
1307	Lougga	Vina	19/11/2014	50	cow (6y)
1308	Martap	Vina	08/11/2014	45	cow (4y)
1350	Banyo	Mayo Banyo	30/11/2014	33	bull (4y)

Note Date of deployment of the GPS device, as the date of retrieval, depended on the availability of the herds owners and locations of these herds. In brackets are reported the ages of the cattle that were selected to be tracked.

herdsmen or keepers we aimed at obtaining information on the daily habits of the cattle and events happening during this long distance migration through the use of pictorial diaries (G_2) provided to these keepers accompanying the animals (see Section 3.5.3 and Appendix C).

As an additional data collection approach, upon return from the transhumant migration, in May 2015, a questionnaire-based interview with herdsmen or keepers (G_3) was carried out to obtain information on the past 6 months of herd mobility (see Section 3.5.3 and Appendix C). The questionnaire took 15-20 minutes to administer and focused at collecting information on the daily routines of the herd and herd management practices, including animal health conditions, interactions with livestock or wildlife populations and on trading activities, during the transhumance period.

7.3.3 Data processing

As in the areas where the sampled transhumant herds grazed during the data collection period the GSM network coverage was poor and data transmission insufficient, GPS positions were predominantly stored in the backup memory. At the end of the data collection in May 2015 all of the collars were retrieved from the cattle. The collars (G_1) were then shipped to the producer to manually download the stored data which were then sent as .csv files. The datasets obtained from each collar unit included the complete record of the GPS coordinates and of the travelling speed (km/hour) at each recording event (every two hours). The GPS sampling frequency was set to every 2 hours in accordance with other studies tracking cattle in similar settings (Schlecht et al. [2006]; Perotto-Baldivieso et al. [2012]; Anderson et al. [2013]). More frequent GPS sampling would have provided the opportunity to increase the accuracy of the estimates of distances travelled between GPS locations over the observation period (Ungar et al. [2005]; Johnson and Ganskopp [2008]). However, recordings of GPS locations too closely in time tend to be positively correlated, decreasing the accuracy of the captured location and, therefore, affecting also the estimation of the distance over the time of observation (Perotto-Baldivieso et al. [2012]).

Along with the retrieval of the GPS devices the pictorial diaries (G_2) provided to the keepers escorting the animals were collected. The hard copies of the questionnaires carried out with the herdsmen and keepers (G_3) upon return from the transhumance were manually transcribed to pre-designed (Microsoft) Excel 2007 spreadsheet and stored as a .csv file.

7.3.4 Data analysis (G_1 and G_3)

A combination of traditional descriptive and visual analytical approaches were applied to characterise the transhumance trajectories of the tracked cattle and to assess the general characteristics of the period of mobility of the tracked herds. The recorded GPS coordinates and speed of travelling of the tracked cattle were assessed using traditional descriptive tools such as histograms and interquartile box plots.

The distance traveled between any two consecutive recorded GPS locations was estimated in kilometres using latitude/longitude (degree) georeferences and calculating the euclidean distance between these GPS locations. The distances travelled were also aggregated at daily and weekly intervals in order to assess the variability of the distances travelled by the different tracked herds over different time intervals. This was then also used to characterise the range of daily distances traveled and to estimate the daily mean distances travelled during each of the weeks of observation.

A hot spot analysis (Lu [2000]) was carried out to assist identification of locations with unusual high concentrations of data points, identifying spatial clusters where tracked herds were more frequently recorded during the period of observation. The objective of this analysis was to reflect the patterns of activity of the transhumant herds, (or “activity locations”), during the entire period of observation. In order to identify and count these hot spots 2D kernel density were used (Venables and Ripley [2002]). Kernel density estimation is a non-parametric method where a symmetrical kernel function is superimposed over each GPS location and requires the definition of a spatial and temporal parameter (Carlos et al. [2010]). The spatial parameter, or bandwidth value, corresponds to the roaming radius while the temporal parameter defines the minimal duration of stay at a given location to qualify as a significant stop. For the purpose of this study, the temporal parameter was given by the time between any two GPS recordings (2 hours) and the spatial parameter (bandwidth) was set to a cell size of 500 m (Venables and Ripley [2002]).

All analysis and graphics were performed in R statistical software (R Core Team [2013]) (version 3.2.3) using the *raster*, *rgdal*, *ks* and *ggplot2* packages.

7.4 Results

7.4.1 Collar and data retrieval

Out of the 10 deployed GPS collar units (G_1) all of them were successfully retrieved from the animals in the month of May 2015. However, complete recording of the spatial locations for the whole period of observation were successfully dowloaded from only 7 collars. Among the seven collars with complete records, one collar belonged to a herd whose herder finally decided not to go on transhumance. Partial recordings from the three collars were due to the memory being overwritten with later locations as a consequence of poor GSM network coverage which resulted in excessive use of the on-board storage. In one case (collar 1350) the recordings were almost entirely unavailable, likely due to a concomitant technical failure of the GPS device. Data retrieved from collars 1303 and 1307 were only partially complete, 42% and 44% of the transhumance days, respectively. Because of this, the three collars were excluded from the analysis along with the herd that failed to leave on transhumance (1306), leaving data from 6 collars for analysis. The 6 herds that were successfully tracked during the seasonal transhumance showed very different migratory patterns (Figure 7.1).

The pictorial diaries (G_2) provided to the accompanying keepers failed to generate the expected data because of the lack of compliance from the participants. As a result no further analysis was possible on the information provided by this approach.

Out of the 10 questionnaires carried out with the herdsmen and keepers (G_3) at the time of the retrieval of the GPS units, 9 interviews provided complete information. One interview was not carried out as the owner of the herd reported having cancelled the seasonal transhumance right at the beginning due to personal reasons and, therefore, he maintained the herd around the usual grazing area. Therefore, in addition to the complete GPS recordings and questionnaire data from 6 herds a further 3 herds provided questionnaire data (G_3).

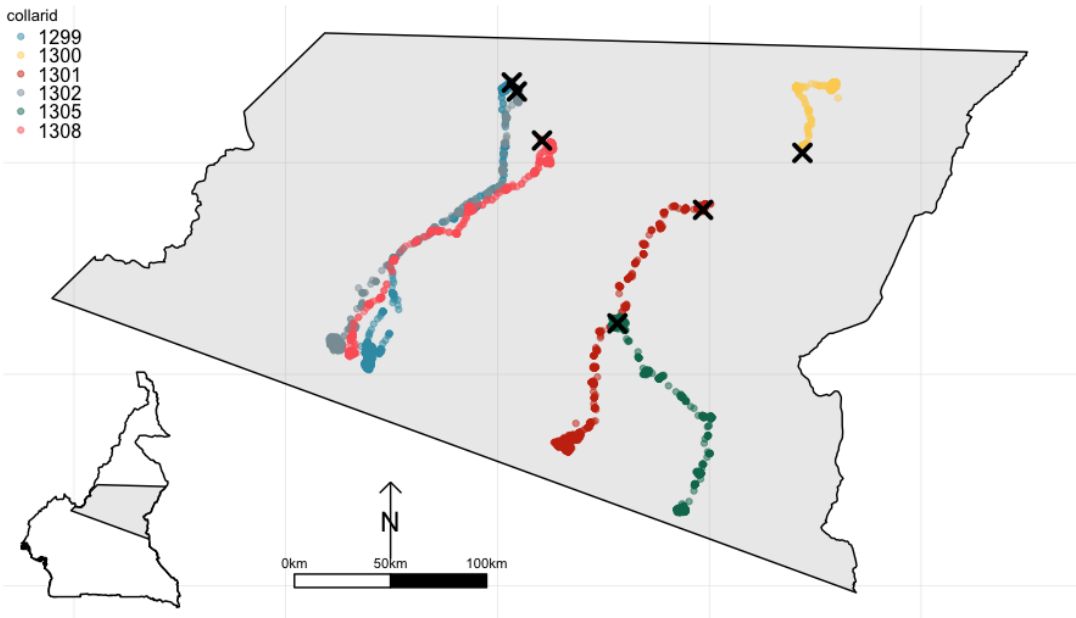

Figure 7.1: **Transhumance trajectories of the tracked herds.**
The trajectories of each GPS collar are displayed with a different colour on the section of the Cameroonian map. The black X indicates the starting point of the transhumance.

7.4.2 Spatial movements of the tracked herds

The six herds that went on transhumance showed very different migratory patterns (Figure 7.1 and Table 7.2). In most cases (5/6) the seasonal migration was towards the southern Regions of the country (herd 1299, 1302 and 1308 to the Centre Region; herd 1301 and 1305 to the East Region), while in one case it was towards the north, to the North Region (herd 1300). The three herds migrating to the Centre Region went around the area of the Mbam and Djerem National Park (about 170km of distance from their origin), while the two herds migrating to the East Region around the Pangar and Djerem Reserve (about 150 and 120km from their origin, respectively). By the contrary, the herd migrating towards north stayed in the Mayo-Rey Division of the North Region of Cameroon, about 50km from its origin. The duration of the transhumance was relatively similar among the 6 herds and varied between 26 and 32 weeks. Although the straight line (euclidean) distances between the origin and the final destination of the transhumance ranged between 53 and 170km, the overall estimated distance covered by the herds during the whole duration of the transhumance was relatively similar, ranging between 633 and 763km.

7.4.3 Speed of herds movements

The speed of movement of the tracked herds, as recorded every 2 hours, ranged between 0.1 and 7.8 km/hour (Figure 7.2A). The overall median speed of each of the 6 herds during the whole period of observation ranged between 0.48 and 1.02 km/hour (Figure 7.2B). Although the absolute range of the recorded speed was approximately similar between the herds, herds 1305 and 1308 displayed a wider interquartile range of speeds compared to the other herds (0.48-1.82 km/hour

Table 7.2: **Distances travelled by the cattle herds during transhumance.**
The total distance covered during the entire period of observation, the mean distance travelled per day (standard deviation in brackets) and the distance between the two most far apart locations are all reported in kilometers. The duration of the transhumance, in weeks, is estimated from the week the herds left the grazing location in the Adamawa Region until the week they returned to same location.

Collar num.	**Total distance covered** (km)	**Median distance per day** (km)	**Shortest distance origin/destination** (km)	**Transhumance duration (weeks)**	**Final transhumance destination**
1299	746	4.14 (2.21)	170.9	26	Centre Region
1300	730	3.32 (1.74)	53.3	32	North Region
1301	763	3.97 (2.03)	154.0	29	East Region
1302	633	3.23 (2.01)	172.7	28	Centre Region
1305	649	3.55 (1.91)	115.5	27	East Region
1308	726	3.63 (1.56)	157.1	29	Centre Region

and 0.51-1.91 km/hour, respectively) (Figure 7.2B).

Overall, the speed of the herds showed a consistent pattern across the 24 hour cycle (Figure 7.3). The mean speed of the herds tended to increase between 06:00 and 18:00 hours. In addition the absolute peaks of speed were recorded within this time window. Nevertheless, across the whole study period all the 6 herds were also recorded to have moved at higher speeds, of at least $4km$/hour, at all of the recorded time points throughout the 24 hour daily cycle (Figure 7.3). In other words, herds were recorded making significant movements even during the night.

7.4.4 Daily patterns of movements

The daily estimated distance travelled by a herd ranged between 0.3 and 22.9 km/day, with 86% of herd-days below 5 km/day while on transhumance (Figure 7.4A). The median distance covered per day by each herd over the whole transhumance period ranged between 3.2 and 4.1 km/day (Figure 7.4B). Looking across the period of transhumance, there were relative short periods when the daily distances travelled were above the overall mean daily distance. These were mainly at the start and end of the migration and reflected movements from and to the main transhumance grazing zone (Figure 7.5). However, in 3 cases (herds 1299, 1305 and 1308) higher mean daily distances were also travelled during other weeks of the transhumance. Overall, these periods of higher mean daily travelled distance tended to last between 1 and 3 weeks (Figure 7.5). Herd 1300 was an exception, with an overall shorter weekly mean daily distance travelled across the whole period of observation.

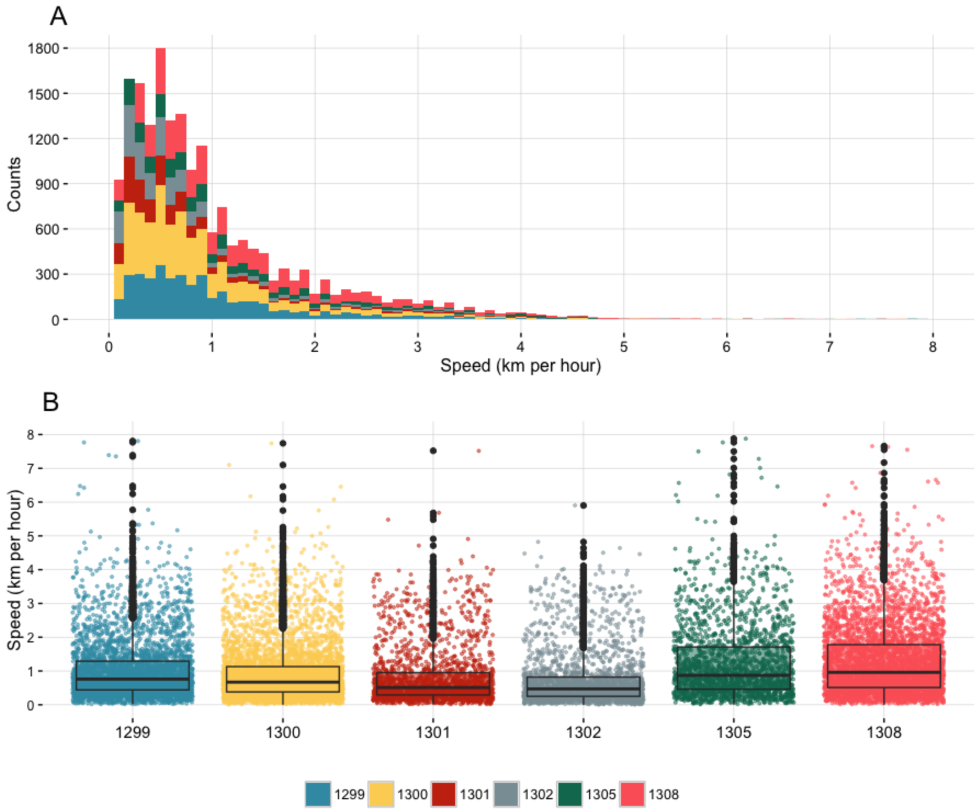

Figure 7.2: **Speed of movement of the transhumant herds (in km per hour).**
A: Distribution of the recorded speed of movements at each GPS captured location for the tracked cattle (km per hours on the x axis and counts on the y axis).
B: Boxplot of the recorded speed of movements at each GPS captured location for each tracked cattle (x axis). For each box the dots refer to the the recorded speed at each GPS captured location, the upper and lower “hinges” correspond to the 1st and 3rd quartiles (the 25th and 75th percentiles) and the horizontal line to the median value.

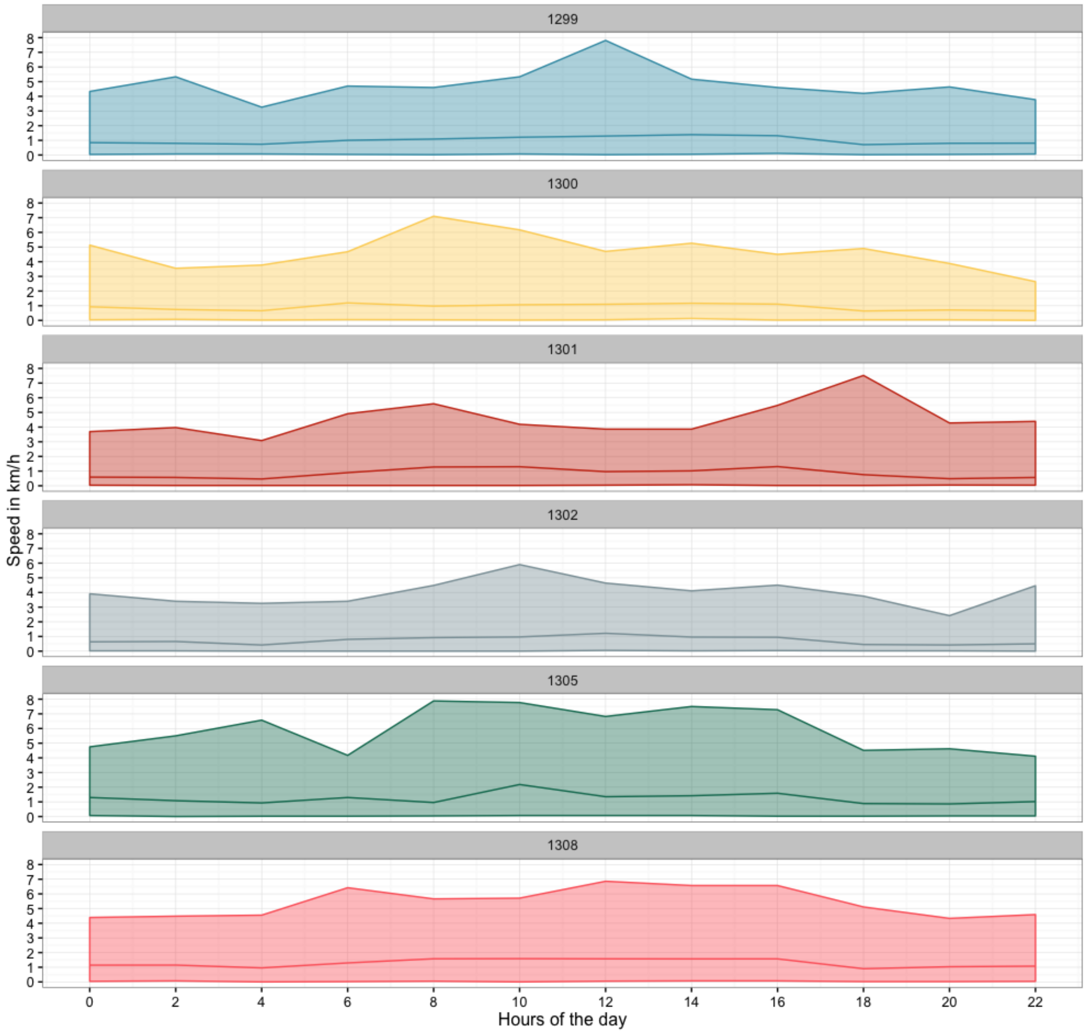

Figure 7.3: **Mean and ranges of the speed over the 24 hours period.** For each tracked cattle the speed of movements was recorded every two hours of the observation period. The middle line represents the mean speed at that hour of the day while the upper and lower lines represent, respectively, the fastest and slowest speed recorded at that specific time during the observation period.

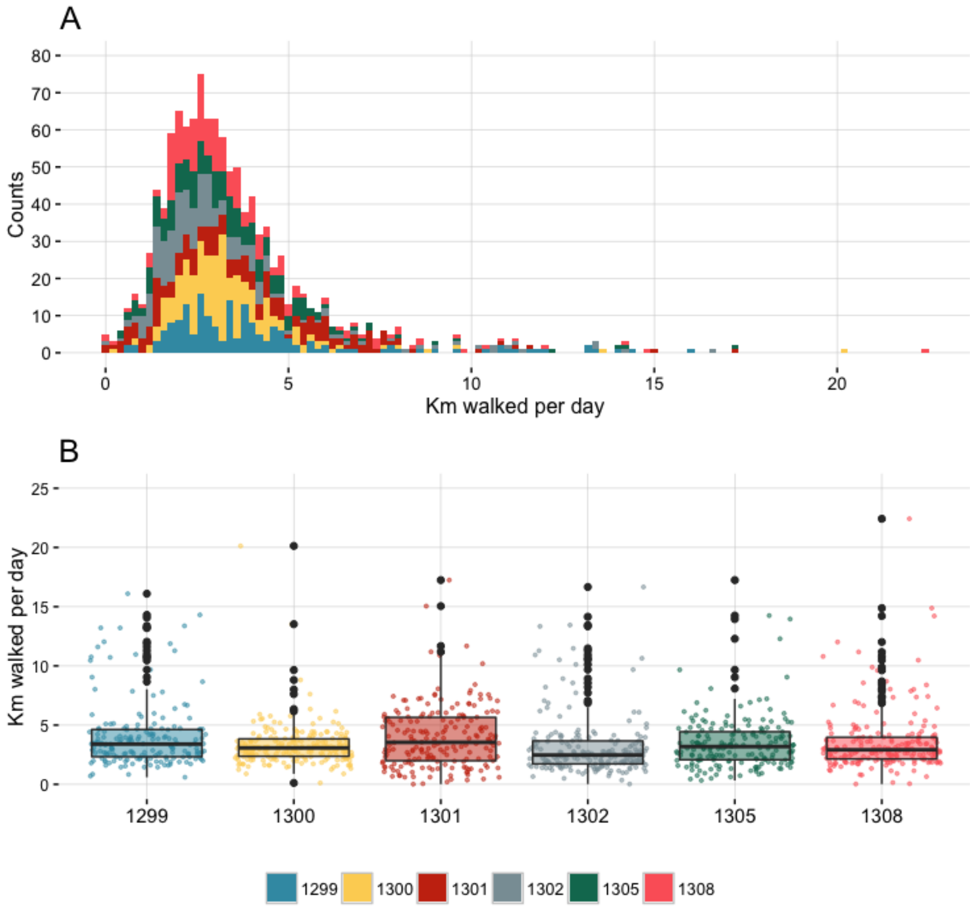

Figure 7.4: **Daily distances covered by the transhumant herds.**
A: Distribution of the daily distances walked by the tracked cattle (distance in km on the x axis and counts on the y axis).
B: Boxplot of the daily distance travelled by each tracked cattle (x axis). For each box the dots refer to the the daily distance for each day of observation, the upper and lower "hinges" correspond to the 1st and 3rd quartiles (the 25th and 75th percentiles) and the horizontal line to the median value.

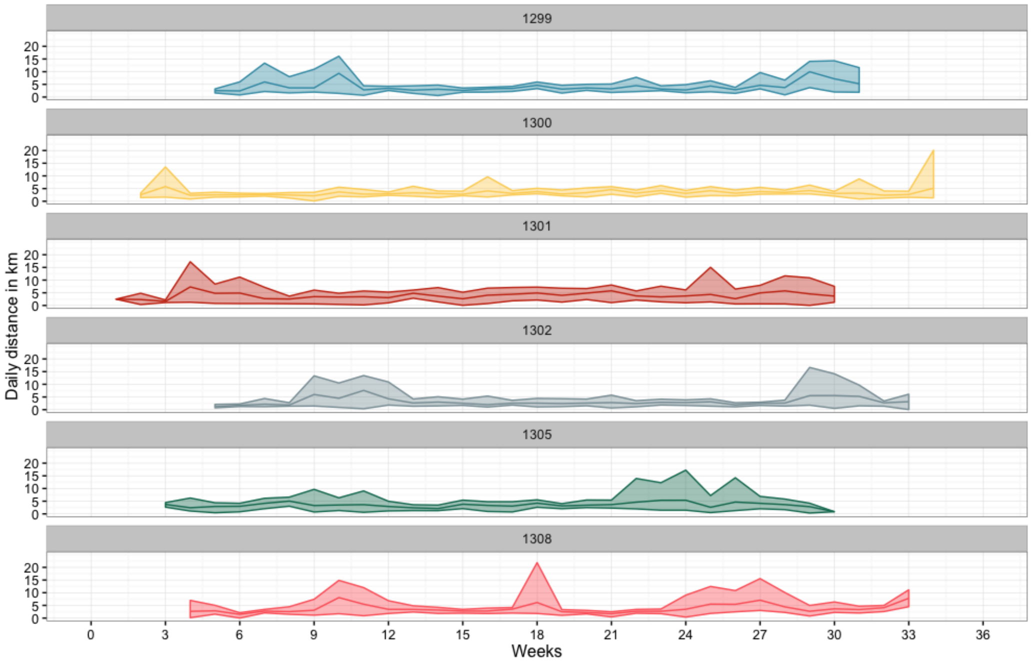

Figure 7.5: **Mean and ranges of the daily distances walked during each week of the period of observation.**

For each tracked cattle the mean estimated daily distance walked during each week of observation is represented by the middle line while the upper and lower lines represent, respectively, the biggest and smallest distances walked in each weeks.

7.4.5 Hot spots, or activity locations, during the transhumance

Figure 7.5 showed that weeks concentrated in 2 particular periods, towards the beginning and the end of the transhumance, had the highest values of mean daily distance travelled. However, in 3 cases (1299, 1305 and 1308) higher median daily distances were also travelled during other weeks of the transhumance.

The hot spot, or activity locations analysis, supported this observation by showing that there were geographical areas where the herds spent longer periods of activity and areas where the herds were only transiting (Figure 7.6). For all of the tracked herds the origin and destination of the migration represented hot spots of activity for the herds. Nevertheless, herds 1299, 1305 and 1308 spent longer periods also in other zones along their transhumance trajectories (Figure 7.6). Unfortunately, the reasons for these differences are not clear and it was not possible to follow up once we had the GPS data, as these were retrieved from the collar device only once the questionnaire was already carried out.

7.4.6 Contacts and interactions with other cattle herds during transhumance

During periods of active trekking and movement towards transhumance destinations or returning back to the usual grazing locations, 5/9 herdsmen reported that >15 cattle herds were usually encountered each day (Figure 7.7A). The four other herdsmen reported routinely encountering 1-3, 4-5, 6-10 and 11-15 other cattle herds per day, respectively. In contrast, in grazing areas such as the transhumance destinations, herds tended to meet fewer other herds per day: only one herdsman reported that more than 15 cattle herds were encountered on an

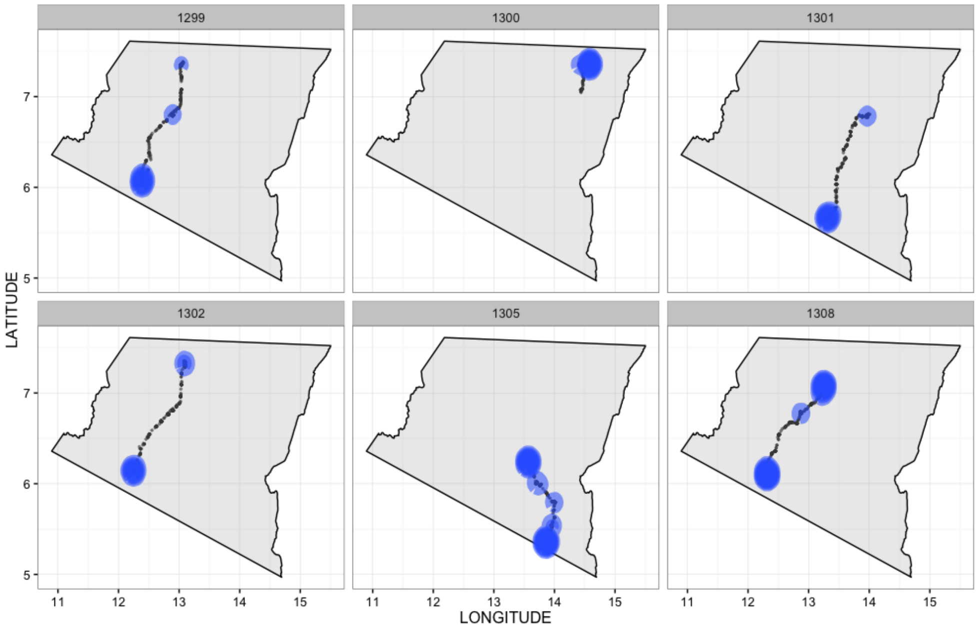

Figure 7.6: **Hot spot analysis of the locations visited during the period of observation.**
Two-dimensional density plots of the recorded GPS locations. The trajectories are displayed by the black dots representing the GPS locations. The size of the blue dots and intensity of the blue colour reflect the occurrence (count) of GPS recordings (counts of observations) at each specific area (e.g.: most of the GPS locations of collars number 1301 and 1302 were recorded in two locations while, on the contrary, the GPS locations of collar 1305 were mainly recorded in 5 areas).

average day at this location, 2 herdsmen reported a mean of 11 to 15 and all the other reported fewer contacts (Figure 7.7B).

The typical duration of these interactions was estimated by 6/9 herdsmen to last less than 1 hour, while 2/9 herdsmen reported a duration of interaction between 4 and 6 hours and 1/9 between 13 and 24 hours (Figure 7.8). Interestingly, two of the tracked herds (1301 and 1305) physically met during the period of observation (Figure 7.9). The encounter happened during the return from the seasonal migration, in a usual grazing location of the herd 1305 but about 59km from the migration origin of herd 1301 and lasted approximately between 4 and 6 hours. This highlights that even herds which for most of the year graze far apart from each other in a pastoral system effectively have the chance to get in contact during these long distances seasonal movements. It is likely that many of the reported daily contacts are in fact with herds not normally encountered at the origin grazing location.

7.4.7 Contacts with other animal species and health issues reported during transhumance

Herders were asked what other animal species had been encountered during the transhumance. Among domestic species, sheep were the most frequently encountered and reported by all the 9 interviewees, followed by poultry (5/9 herdsmen), goats (4/9 herdsmen), horses and dogs (3/9 herdsmen) and pigs (1/9 herdsmen). The most frequently encountered wildlife species were the antelopes (4/9 herdsmen), followed by warthogs (2/9 herdsmen) and buffaloes (1/9 herdsmen) and another unspecified animal (1/9 herdsmen) (Figure 7.10A).

Among the reported health problems faced by the cattle herds during the tran-

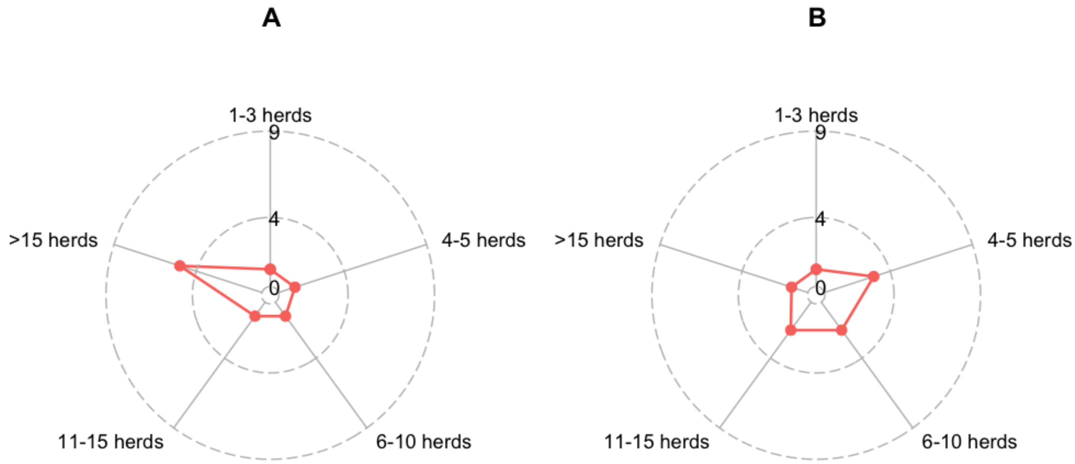

Figure 7.7: **Number of other cattle herds encountered daily during the transhumance period.**
A: Reported number of cattle herds encountered on average every day during the trekking towards transhumance destinations or returning towards the usual grazing locations. The radar plot displays the answers of the interviewees and the red line refers to the number of reports by the 9 interviewees.
B: Reported number of cattle herds encountered on average every day during grazing activities at the transhumance destination. The radar plot displays the answers of the interviewees and the red line refers to the number of reports by the 9 interviewees.

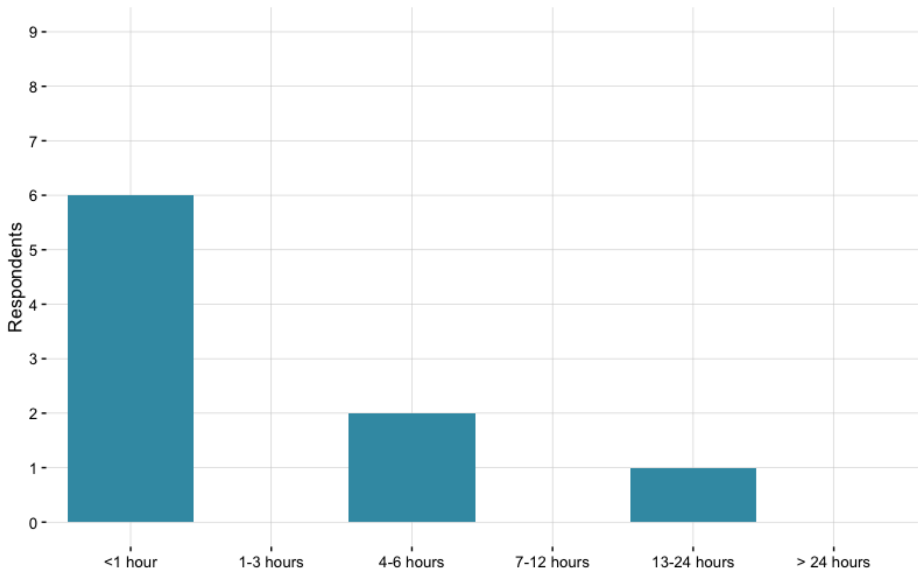

Figure 7.8: **Reported duration of interaction with other cattle herds.**
On the x axis the reported usual duration of interaction with other cattle herds during transhumance and on the y axis the number of interviewees.

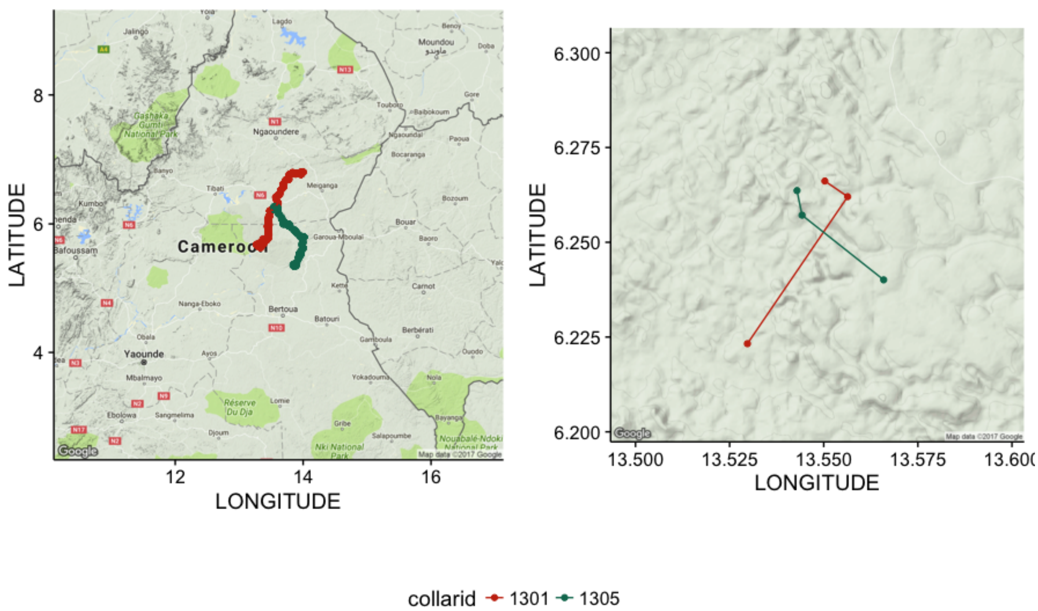

Figure 7.9: **Recorded encounter between 2 tracked herds.**
The herdsmen of these 2 herds (1301 and 1305) reported having met each other at the time of interview. The analysis of the GPS recordings enabled to identify the exact time and location of this encounter. The herds were recorded interacting for about 4 hours between 8am and 12am of the 23rd April 2015, while returning to their respective grazing locations for the rainy season

shumance period, the most commonly reported was trypanosomiasis (7/9 herdsmen) followed by liver fluke (4/9 herdsmen), FMD (3/9 herdsmen), dermatophilosis (2/9 herdsmen) and plant intoxication (1/9 herdsmen) (Figure 7.10B).

Nevertheless, when assessing the causes of death of cattle during the transhumance, accidents were reported as having caused the loss of at least one animal (5/9 herdsmen), followed by disease (4/9 herdsmen) and by plant intoxication (3/9 herdsmen) (Table 7.3 and Figure 7.11A). However, an accident in 3 cases caused the death of only 1 animal and in 2 cases of 2 animals (Table 7.3 and Figure 7.11B). In 3 cases only 1 animal per herd and in 1 case 2 animals in the herd ware lost due to a disease while plant intoxication was indicated as the cause of death of, respectively, 1, 3 and 6 cattle from 3 different herds (Table 7.3 and Figure 7.11B).

Table 7.3: **Number of herdsmen reporting cattle death and trade during the transhumance period.** Reported cattle losses during transhuman were stratified by the cause of death as diagnosed by herdsmen. Reported trade events during transhuman were stratified by whether animals were sold (or purchased) within or outside the trading system .

Reported events	N_H	N_C
Causes of cattle losses		
Accident	5	7
Diseases	4	6
Plant Intoxication	3	10
Cattle trade		
Sale (within market)	4	13
Sale (outside market)	2	4
Purchase (within market)	0	0
Purchase (outside market)	0	0

N_H: Number of herdsmen reporting events; N_C: Number of cattle involved in each reported event.

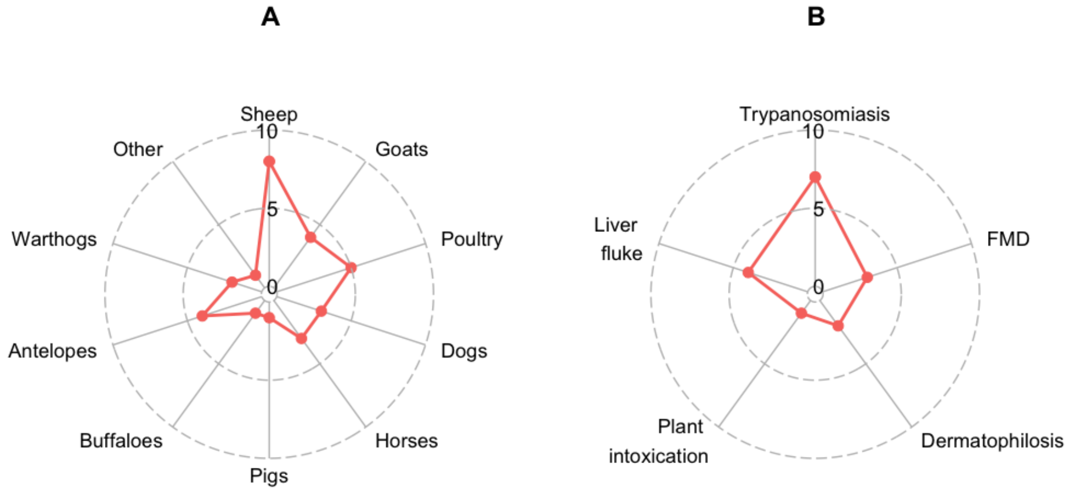

Figure 7.10: **Interaction with other animal species and common health problems reported during transhumance.**
A: Reported species of domestic and wild animals encountered during the transhumance. The radar plot displays the animal species and the red line refers to the number of reports by the interviewees.
B: Reported health problems faced by the herds during the transhumance. The radar plot displays the reported health problems and the red line refers to the number of reports by the interviewees.

7.4.8 Trading activities of the tracked herds during transhumance (G_3)

None of the herdsmen (0/9) reported having acquired cattle during the transhumance period, either from livestock markets or from outside the trading system. However, four (4/9) herdsmen reported having sold cattle at livestock markets during the transhumance, while two (2/9) herdsmen reported having sold cattle outside the trading system (Table 3 and Figure 7.12A). When sold at the market place, respectively, 2, 3, 3 and 5 were sold while 1 and 3 cattle were sold outside the marketing place (Figure 7.12B).

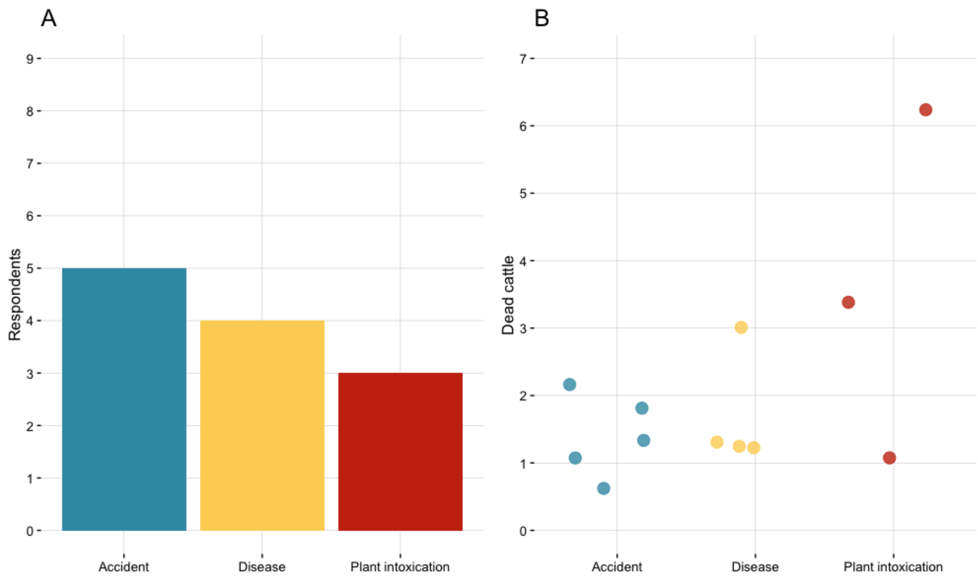

Figure 7.11: **Reported causes of cattle losses during transhumance.**
A: Reported causes of death within the herds during transhumance. On the y axis the number of interviewees and on the x axis the causes of losses that were reported.
B: Reported numbers of deaths for each cause. On the y axis the number of lost cattle and on the x axis the reported causes.

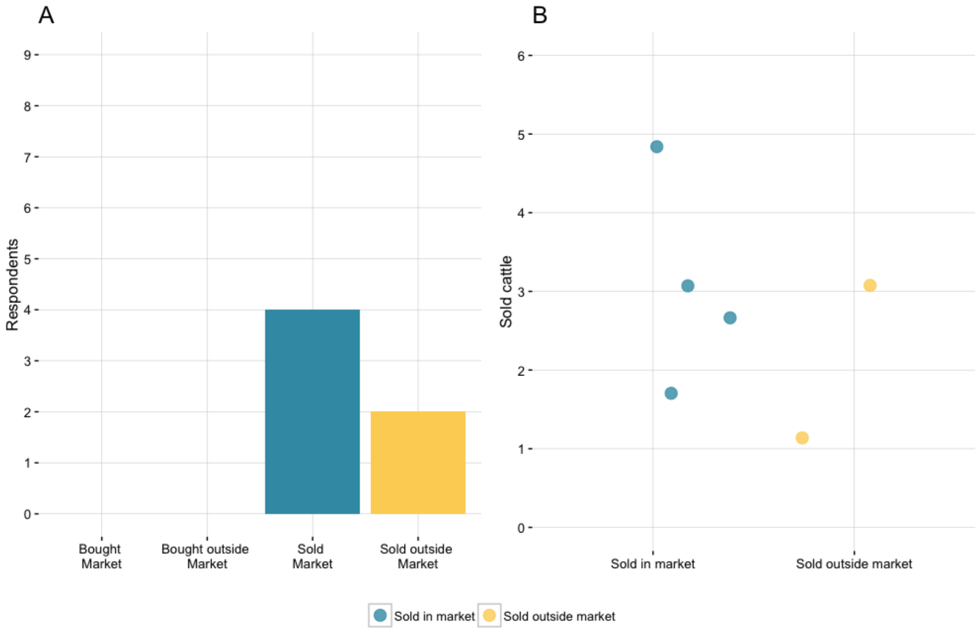

Figure 7.12: **Cattle traded within and outside the trading system during the transhumance.**

A: Interviewees who reported to have sold or bought cattle within and outside the trading system during the period of transhumance. On the y axis the number of interviewees.

B: On the y axis the number of reported cattle sold and on the x axis if they were sold at markets or outside markets.

7.5 Discussion

In SSA, seasonal livestock mobility is an important adaptation strategy for pastoralist communities. It represents a key strategy for these households to take full advantage of the variability of the natural resources in their ecosystem to sustain their livelihoods (McGahey, D. [2002]). In Cameroon, more specifically, trade-related and pastoral patterns of livestock movements coexist at local, national as well as international levels all year round (Njoya et al. [1999]). During the dry season the transhumance represents a common practice for many cattle herds across the country in order to cope with ecological and environmental constraints. In particular, in the Adamawa Region this management practice has been previously reported as being implemented by around 50% of the cattle herders (Bronsvoort et al. [2003]; Kelly et al. [2016]) and by around 25% of the interviewees in this current project (Section 4.3.13 of this thesis) representing, therefore, an integral component of the livestock production system. Nevertheless, there is still little knowledge currently available in Cameroon about the transhumance patterns, in terms of the trajectories, distances, duration, activities and management practices in order to better understand cattle mobility in the country and for assessing the interactions between pastoral and trading systems.

This pilot study showed that applying GPS collar devices to track single animals and their herds represent a feasible approach in this context. All of the deployed collars were successfully retrieved, however only 60% of them contained a full dataset of GPS locations recordings for the entire period of transhumance. While one herd finally did not go on transhumance, the failure rate of the GPS devices was most likely due to GSM coverage failure or the lack of a uniform GSM network in the areas visited by the herd during their transhumance. This led the tracking devices to store the GPS positions on the memory card, instead of transmitting it to a server through the GSM network, and probably an eccessive storage has led to exhausting the memory space and therefore loosing all the subsequent captured GPS positions. An additional problem likely to have contributed to this failure could be due to the topography of the areas where these herds were located and the presence of potential physical obstacles obstructing the correct reception of the satellite signals with the GPS locations.

Nevertheless, 6 collars provided a full dataset of GPS locations for the whole duration of the transhumance (a 7th herd finally did not go on transhumance). This study, hence, showed the usefulness of GPS technology in tracking cattle movement even under prolonged semi-arid conditions and in very remote areas of SSA. The period of transhumance lasted for more than half of a year for all of the tracked herds, and ranged between 26 and 32 weeks. Most of the tracked herds leaving the Adamawa Region were directed towards areas located in southern Regions of the country (Centre (3) and East (2)), while 1 transhumant herd was directed to the North Region.

Pairing animal movements with associated animal activities is of increasing interest in animal behavioural and ecological studies. About 95% of the 40 different behaviours that cattle are acknowledged to engage in, can be classified into one of four main activities defined as foraging, travelling, standing or lying (Anderson et al. [2013]). While travelling, cattle herds are known as having a 3 times higher mean speed compared to grazing, and the travelled distance within a specific time window can be used as an indicator of the activities, including travelling, carried out by the herds (Šárová et al. [2010]; Homburger et al. [2014]). Travelling has been observed as an activity accounting for between the 6 and the 12% of the overall observed time when tracking cattle herds (Ungar et al. [2005]; Homburger et al. [2014]). Although we cannot be completely confident in inferring the activity of the herds from the distance travelled or from the travelling speed, the proportion of daily distances covered during the observed period and the distribution and the range of speed recorded in the present study were in line with the findings of these previous studies. In less than 15% of the recorded days the distance covered was greater than 5km, showing that also in this pilot study herds were not travelling long distances during most of the observed days. In addition, an approximately equivalent proportion of the recorded speed showed to be around 3 times greater than the speed considered compatible with a grazing activity ($<1km$/h), therefore, supporting this interpretation. Nevertheless, as integration of GPS and motion sensors (e.g. proximity devices) would provide the optimal approach for an accurate determination of animal activity, caution in making absolute conclusions based only of GPS data should be made.

The findings of the current study suggest that the bulk of the travelling was condensed within a relative short time period. Herds tended to travel between distant locations in relatively short periods of 1 and 2 weeks, either at the beginning or end of the observation period, or also during other moments of the transhumance. The analysis of the activity locations further supports this finding showing that all of the herds spent longer periods moving short distances, either in the areas of origin or of final destination of the transhumance. However, also revealed that 3 herds spent relatively long periods moving short distances also in other zones along their transhumance trajectories, showing that in these cases herds stopped at different grazing areas and did not only moved from an origin A to a destination B and back.

From these results, it is apparent that seasonal cattle transhumance in Cameroon, rather than a simple transit between two locations, is a complex journey including multiple grazing areas and lasting a significant amount of time (sometime even greater than half of the year). Furthermore, the trajectories of all of the three tracked herds originating from the eastern part of the Vina Division towards the Centre Region highlights the presence of common migratory routes. If the presence of such migratory routes is further confirmed and if these harbor zones are also confirmed to be common transhumance destinations for a high number of cattle herds and for such long periods, these results highlight the importance of considering them also as high cattle density areas of the country, at least for part of the year.

During migration, cattle herds, as they move towards grazing transhumance areas, tend to have higher numbers of contacts with herds compared to when they are sedentary at grazing locations. These differences in contact rates during the traveling and grazing periods of transhumance could have diverse implications for the epidemiology of infectious diseases. In particular, longer grazing periods in multiple locations could increase the chances of coming into contact with geographically limited or seasonally abundant diseases, such as trypanosomiasis and multiple parasitic diseases (Macpherson [1995]). Consequently, it is not surprising that trypanosomiasis and liver fluke were the most commonly reported diseases affecting the migrating herds. In fact, in Cameroon, these diseases are particularly prevalent in areas where rainfall is above 1000 mm per year, offering greener pastures and greater water availability for their vector populations to flourish (Awa and Achukwi [2010]). In the present study FMD and dermatophilosis ranked as 3rd and 4th most reported diseases affecting the transhumant herd underlining the critical role of animal movements for the maintenance and circulation of these diseases in the country. This is in slight contradiction with the findings of the study carried out in the cattle trading system in Chapter 4 where these diseases represented by far the major reported health problems of traded cattle. Obviously the present pilot study can rely only on a very small dataset and any laboratory support, nevertheless highlights potential differences in the roles of trading and pastoral mobility for the epidemiology of the different infectious diseases in the country.

The reported spatial overlapping between multiple cattle herds and between cattle herds and other domestic or wildlife species in this study highlights the opportunity for the maintenance and dispersal of infectious diseases during the seasonal transhumance. This finding underlines the importance of monitoring at least major routes of migration or main destination areas as they might represent potential disease transmission sites. Despite the variability in contact rates, the interactions between cattle herds, both during travelling or at grazing areas, were reported mostly to have relatively short durations (<1 hour). However, the close proximity between animals during this types of interactions is sufficient for the transmission of highly infectious diseases such as FMD, particularly during the peak of the infectious periods (Sellers and Parker [1969]; Mardones et al. [2010]).

Further to these daily patterns of contacts, the observation of two herds from very different origins contacting each other during transhumance highlights the importance of the high levels of mixing that occur not just locally, with communal grazing, but at long distances via transhumance migrating pathways. The higher density of wildlife in the grazing zones, including antelopes and buffaloes, also highlights the greater potential for contacts with reservoirs, such as buffaloes, or risk of spillover of disease into wildlife populations as has been observed by others (Macpherson [1995]; Bronsvoort et al. [2004b]).

Infectious diseases are the major animal health problem for the livestock sector at a country and regional level. However, it is interesting to notice that the most common reported cause of death among the transhumant herd was by accidents, followed by disease and plant intoxications. Bearing in mind that these were only anecdotal reports from a questionnaire-based interview, these findings suggest that transhumance presents additional challenges for the management of the cattle herds. Trekking for long distances could pose additional risks for various types of physical accidents occurring to the animals including higher exposures to environmental hazards, as in the case of plant intoxication.

Interestingly, during the transhumance period, 5/9 of the herds under study also reported to have sold cattle, either within or outside the formal trading system. Livestock markets are known to be transmission hotspots and key nodes in the epidemiology of multiple infectious diseases (Keeling and Eames [2005]; Robinson and Christley [2007]; Dean et al. [2013]; Vallée et al. [2013]). This interconnection shown in the current study highlights the role of markets also as an interface between the pastoral and the trading systems, underlining their key role for risk-based approaches to surveillance, control and communication strategies. Nevertheless, the finding that two of the tracked herds not only had overlapping areas of migration and of activities but also directly get in contact in the field despite being originated from very distant locations (˜90 km), underlines the heterogeneous and complex system of connection and interactions of the livestock sector in this pastoral systems.

It is important to consider that the restricted number of GPS units used for this study and the small number of questionnaire-based interviews carried out limit the conclusions that can be drawn by this study. Simultaneously, a potential source of bias might be represented by the accuracy of GPS data, which represents one of the principal determinants of the quality of geographical position data. The accuracy of GPS coordinates might have been affected by atmospheric conditions, satellite geometry, obstruction of satellite signals by physical obstacles, satellite or receiver clock error as well as topography and the presence of structures that may interfere with the signals communications (Moen et al. [1997]; Ganskopp and Johnson [2007]; Buerkert and Schlecht [2009]). Another potential source of bias of the data could have been represented by the GPS sampling frequency as prolonged GPS sampling intervals could lead to slight underestimation of the distance travelled between subsequent recorded location (Johnson and Ganskopp [2008]). This effect is mainly due to the fact that the euclidean distance assumes a straight line of movement between two recorded GPS locations. According to these considerations frequent short GPS sampling intervals would theoretically provide a more suitable framework to better estimate the distances travelled (Ungar et al. [2005]; Johnson and Ganskopp [2008]). On the other hand, however, GPS locations recorded at close points in time tend to be positively correlated, decreasing the accuracy of their true location and, therefore, of the estimated distance between the true locations (Perotto-Baldivieso et al. [2012]). The degree of similarity between subsequent recorded GPS locations, and the level of autocorrelation of these recordings, may, therefore, bias the estimation of the distances and, as a suitable approach to minimise this effect, time intervals separated by at least 1 hour have been suggested (Perotto-Baldivieso et al. [2012]). Given the overall objectives of the present study, the challenges of applying this technology in the study area and the trade-offs between sampling frequency, data accuracy, battery life, memory constraints, landscape characteristics and financial limitations of this research a sampling interval of 2 hours between each GPS location recording was the compromise as used by other studies tracking cattle in similar settings (Schlecht et al. [2006]; Perotto-Baldivieso et al. [2012]; Anderson et al. [2013]). To the best of my knowledge, this is one of few studies on cattle pastoral mobility using GPS-tracking technology in SSA and showed that remote-sensing can be reliably applied within similar contexts and within pastoral societies to increase the understanding of the implications of cattle mobility in the epidemiology of disease transmission.

While obtaining empirical observations about a limited sample of cattle herds for the entire duration of the seasonal transhumance this study could highlight the presence of a spatial and temporal overlapping of herds as well as the opportunity for direct contacts between herds which spend most of their time very far apart. Obviously this represents a risk for the dissemination of various infectious diseases, both epidemic and endemic, and needs to be acknowledged and considered when designing and planning surveillance and control strategies. This pilot study provides a general picture of this seasonal migration, describing a sample of trajectories and some aspects of the cattle management practices of the transhumant herds as a preliminary attempt to fill the knowledge gap regarding this common seasonal mobility in the country and the region as a whole.

7.6 Conclusion

Seasonal cattle transhumance has been shown to be not merely a transit between an origin location and a destination but rather a more complex journey of a long duration, even greater than half of the year. During this period cattle herds can also have multiple 'activity locations' where spending relatively long periods of stay and intensively interact with other herds, as well as with other domestic and wild species.

The transhumance poses relevant challenges for the herds and for the herdsmen. The reported diseases affecting cattle herds were slightly differing with the findings from the cattle market study, ranking trypanosomiasis and liver fluke as the major health problems only followed by FMD and dermatophilosis. Transhumance challenges also included environmental and security hazards that have to be faced during this long distance movements across a variety of landscapes.

Cattle transhumant movements have shown to be not totally disconnected from the formal cattle trading system, highlighting the complexity of this heterogeneous pastoral livestock system in the country and the need for better understanding this framework in order to progress towards the control of livestock diseases. Further, to increase the understanding of disease transmission between livestock and wildlife will require to use similar remote-sensing technology on both domestic and wildlife species that have been found to interact with the cattle herds in of areas overlapping activity, where frequency, duration and nature of contacts could be accurately quantified.

In conclusion, increasing knowledge and comprehension of transhumance, migratory routes and management practices may help improving the understanding of the epidemiology of major infectious diseases in the area. This is of particular importance for rapidly spreading infections, such as FMD, and for the design of more informed strategies for their surveillance and control in the region.

Chapter 8

General Discussion

8.1 Introduction

In West and Central Africa rapid urbanisation and per capita consumption of animal-source foods are projected to continue rising and even to accelerate in the short-medium term (Alexandratos and Bruinsma [2012]). These drivers are likely to trigger relevant changes in the livestock sector in the region, including increasing the movements of live animals and animal products. In Cameroon, where the livelihood of most of the rural population depends on the agricultural sector, livestock mobility represents a central economic activity in the livestock value chain as well as a central strategy of adaptation to the ecosystem. However, livestock movements are known to be also key in disease dynamics and a major driver in the transmission and dissemination of multiple infectious diseases (Fèvre et al. [2006]; Ortiz-Pelaez et al. [2006]; Robinson and Christley [2007]; Dean et al. [2013];).

The general aim of this project was to develop a methodological framework to contribute to improve knowledge and understanding of cattle movements and their implications for disease spread in Cameroon, where the livestock sector is predominantly related to cattle production. In order to achieve this aim, different studies were undertaken to fulfil a number of objectives.

8.2 Summary of the key findings

The study of livestock markets, in the major cattle production areas of Cameroon, and of the cattle trading system, across most of the country, highlighted the presence of 4 main classes of cattle markets: local collection points, sub-regional trading points, regional markets, relevant for both national and international trade, and primary markets, mainly for human consumption or export of cattle. Across the study area the cattle trade volume, despite peaking in December in the dry season, was consistently higher during the rainy season (May-September) and accompanied by a lower mean price per head of cattle compared to the dry season. The Adamawa was the Region with the highest number of traded cattle, representing the main cattle supplier for the southern Regions of the country. Multiple livestock infectious diseases have been reported affecting cattle within the trading system, highlighting the key role of livestock markets for their transmission and dissemination.

A highly directional movement of traded cattle was observed to flow from production Regions, in the North and Centre of Cameroon, towards consumption Regions in southern Cameroon and towards neighbouring countries on the southern border. The large geographical distances and the national boundaries did not represent a barrier to the potential dissemination of infectious diseases in this region of SSA. This cattle trade network was very stable throughout the year. Areas of clustered markets, isolated to others, coexist with long distance connections epidemiologically linking both neighbouring and non-neighbouring countries in the region. A relatively small proportion of livestock markets (about 20%) represent the functional core of the trading system providing the opportunity for targeted surveillance, control and communication interventions.

The directional flow of traded cattle over the markets' network was accompanied by an evident price differential between the cattle production Regions and the markets in the main urban and bordering centres of southern Cameroon. The study of live cattle price at markets in production zones (Adamawa and West Regions) showed the heterogeneity of the factors contributing to price formation, highlighting a relation between the structure of the trading network and the price of traded cattle. A steady positive relation was highlighted between price and the centrality of the market within the trading network, in particular, with a higher number of incoming connections associated to a higher cattle price. Animal related factors, such age and sex, were also clearly contributing to price generation, despite other phenotypic traits likely to affect the price (e.g. animal weight and breed) could not be included in the analysis. Although the characteristics of this pastoral context limit the generalisation that can be drawn by this study at a national level, the distribution of cattle populations were shown to have a non linear relation with the cattle price generation.

The study of cattle transhumance showed that the specific characteristics of this management practice differed across the Regions under study. Nevertheless, across the whole study area about 35% of the market stakeholders reported undertaking seasonal migrations highlighting the spatial and temporal overlapping, and the common opportunities for direct contacts and interactions, between herds of distant origins and with other domestic and wildlife species. Transhumant herds were also observed to be connected to the cattle trading system, underlying the complexity of the heterogeneous livestock system in the country.

Although it was not possible for security reasons to visit and extend this research to the North and Extreme North Regions of the country, combining the main findings of these current studies could provide valuable information for animal health management in the whole country. This information would be particularly relevant for designing targeted and more cost-effective monitoring and surveillance interventions as well as communication strategies.

8.3 Limitations

As previously discussed, it was not possible to physically visit and collect the required data from the North and Extreme North Regions of the country. As such, we are aware that this study missed an established direct pathway of cattle trade, known to flow from high livestock production regions in Central Africa towards countries with a high demand of animal and animal products in West Africa (e.g. Nigeria) passing through the Extreme-North Region of Cameroon.

In this work, predominantly focusing on the cattle trading system, the scale of both the across-country and cross-border cattle movements might have been underestimated, particularly the seasonal transhumant mobility. In addition, mainly focusing on the movement of cattle between markets we could not investigate alternative pathways that may determine pathogen transmission between markets, such as movements of other animals, people and vehicles.

One of the main shortcomings of the survey conducted with the market stakeholders, as well as with the transhumant herders, is represented by the convenient sampling. However, the very dynamic nature and diversity of the livestock markets, and the complexity of engaging herdsmen willing to have their herds tracked during the transhumance, prohibited any more statistically robust approach to the sample design.

Finally the restricted number of GPS devices used in this thesis and number of questionnaire-based interviews carried out to study the seasonal transhumance limit the conclusions that can be drawn by this study. Due to the vulnerability of this technology in a particularly challenging environment such as in the case of this study, some of the devices failed to efficiently record the expected data.

Despite these limitations, this thesis provides a solid base to understand the current system of trade-related, as well as pastoral, cattle movements in the country. In addition, it provides indications of their implications for infectious diseases surveillance and control, contributing to narrowing the knowledge gap about the complexity of livestock interactions at a local, national and regional level.

8.4 Recommendations and overall conclusion

Current international standards govern trade in livestock, and livestock products, from the perspective of preventing the spread of major animal diseases. The presence of TADs and, therefore, the burden of the costs for their regulation, management and control is key to the development of livestock production in Cameroon, as across the whole SSA region. This study highlighted the epidemiological interconnection between neighbouring and non-neighbouring countries in the region, underlying a context where national strategies are likely to have limited effectiveness if developed alone and in isolation. In contrast, regional coordination for designing and implementing prevention, mitigation and control strategies for infectious diseases is essential to improve animal health in such a heterogeneous context.

Data on animal movements in Cameroon are currently only relatively adequate to enable a general characterisation of the cattle trading movements across the country. The detailed information is only available locally, as currently exclusively aggregated information and data are transmitted along the chain of command of the Veterinary Services. Importantly, the available data were not consistently recorded across the study area and in some cases were incomplete. Additionally, at the market level the information was handwritten and recorded in paper books which were kept on site while official reports, with summaries of aggregated information, were transmitted to the relevant authorities. This recording system made it very complex and extremely time consuming to insert in a database, cross-check, process and analyse the data. This current traceability system needs to be developed both in relation to the type of data collected as well as in the consistency across the country.

The analysis and modeling of the network of cattle trade in Cameroon and the identification of the key markets was complex, but sufficiently robust to be standardised and potentially included in an automated analytical system. Ideally, this would also enable further development of the modeling, not only to manipulate the network for identifying the key markets, but also to study movements of other livestock species, and eventually to simulate the spread of specific infectious diseases and the potential impact of alternative control strategies. Preventive measures targeting these key markets as part of surveillance strategies would also provide the potential to increase their detection sensitivity, and their cost-efficiency, for multiple diseases, particularly compared with randomly implemented interventions.

Although an animal identification and registration scheme would represent an ideal step for increasing traceability and for the enhancement of animal health management and the overall competitiveness of the livestock industry, this approach requires considerable financial and technical resources. A much simpler approach, but also more readily applicable in the short term, could be the development of a coherent system for collecting consistent information from livestock markets across every Region of the country. Standardised forms for data collection at the markets, and other premises like abattoirs, and standard operational procedures for the data processing and management could be relatively easily implemented. These procedures and forms should be designed and developed at the central level and provided to the local delegations of the MINEPIA for the data collection. The local delegations should also be provided with the adequate resources not only for collecting the data but also for their electronic registration and transmission.

A standardised collection of information of the traded livestock, including the classification of animals by age, type and breed, the information on origins and destinations of animals along with prices at origin and destination would allow also a better matching of the information, enabling the use of these data for multiple applications. As already discussed such a standardised collection system could also allow applying network analysis techniques routinely. A further improvement to recording the value of animals would be to include the weight of the animal, either directly measured through the use of scales or estimated using body condition scores and methods to assess body weight.

Generally, this type of information, including phenotypic traits of the traded animals, is either missing or not consistently recorded and should be routinely registered across the country to inform pricing procedures and policies to improve the livestock marketing system. In particular, objective animals weight measurements (scales/estimation) would increase accuracy of price formation, reducing room for traders' speculations and increasing protection in negotiations for herdsmen and their households, particularly in the pastoral areas of Cameroon.

Adoption of scales at livestock markets would represent only one of the infrastructural improvements that are required at the trading points. The often dysfunctional infrastructures currently create a favourable environment for the dissemination and circulation of both endemic and newly introduced infectious diseases (e.g. new serotypes or topotypes of the FMDV) and livestock markets end up serving as hotspots for the spread of multiple pathogens. In order to start implementing basic biosecurity measures specific investments should be carried out. As a general example, the lack of quarantine facilities may result in diseased animals entering the selling pen and mixing with other animals, therefore adequate facilities would require dedicated areas to quarantine diseased animal and restraining their movements.

Simultaneously, the improvement of the management practices at the trading points is a priority. The correct separation of the "escorting" cattle from the cattle on sell at the market, and reducing the mixing between different livestock species presented at the market are simple measures which can be easily implemented. It is important that relevant personnel in charge of the market receives adequate training for reducing risks of disease transmission and that the qualified personnel is increased at the markets in order to carry out more specialised procedures, such as clinical inspection of cattle presented.

The infrastructures where livestock trade is carried out are generally constructed and owned either by the local Municipalities or the Government and, usually, jointly managed. Therefore, local and national coordination is essential for the rapid improvements required both relating to the infrastructures and to the management procedures.

Livestock markets represent also an ideal hot spot for outreaching initiatives as well as, obviously, surveillance and monitoring strategies. Market stakeholders, particularly traders, herders and butchers, could be provided with basic information on the major diseases affecting the livestock. Alternative communication strategies could be implemented depending on the Regional and local context and on the type of market (local, sub-regional, regional or primary). Depending on the level of literacy, pictorial information included in leaflets and posters, or oral and short written communications are suitable alternatives. Priority topics should focus on symptomatology, transmission and the at-risk practices for the dissemination of key diseases as well as for their treatment and containment and on procedures for mitigating these risks. Although this information should primarily focus on diseases reported in this study as high priorities for traded cattle, other infectious diseases indicated as affecting cattle in the trading system should also be considered.

Livestock markets represent also an ideal location for the implementation of risk-based strategies for surveillance and monitoring of multiple infectious diseases. Farmer reporting systems are the most common and a key form of surveillance in any country. It is an example, simultaneously, of passive surveillance (e.g. herder seeking help for a sick animal) and of general surveillance (e.g. allows to identify a wide range of diseases). Therefore, developing systems for regular reporting of diseases outbreaks and other animal health conditions, particularly at key markets, would represent an intelligent strategy for increasing surveillance sensitivity, particularly in remote areas not easily accessible throughout the year (e.g. rainy season). These reporting schemes, in combination with awareness campaigns would, simultaneously, empower livestock stakeholders as central actors for the management of animal health and increase the cost-effectiveness of investments. As discussed, key livestock markets provide also the opportunity to implement risk-based surveillance interventions as well as control strategies, enabling to optimise limited available resources. Nevertheless, large geographical distances and national boundaries were found not to represent a barrier for the potential dissemination of infectious diseases in the region, highlighting that national strategies are likely to have limited effectiveness if developed alone and in isolation. Regional coordination for designing and implementing these prevention and mitigation strategies against infectious diseases is essential to improve animal health in SSA.

Transhumance was shown to be an essential herd management strategy for a relevant proportion of the herders interviewed at livestock markets. The adoption of GPS tracking technology was shown to offer opportunities to improve the knowledge about the spatial and temporal resolution of the main transhumance routes across the country. Pastoralism for long has been seen as an economic and environmental activity with little future, however, it is now beginning to be more broadly recognised as a potential source of economic development for rural areas, including in SSA. It is also considered as a viable opportunity to restore and maintain the ecological balance in increasingly drier areas of the planet, particularly when compared to intensive livestock systems.

In conclusion, this study provided a initial characterisation and modeling of the complex and highly interconnected system of cattle movements across Cameroon and of its implications for the transmission and dissemination of multiple infectious diseases. Trade-related movements through an established and constant network of livestock markets across Cameroon and neighbouring countries suggests that a regional approach should be undertaken for its regulation and for mitigating the implications for infectious diseases dissemination. Simultaneously, cattle transhumance was shown to be a common management practice, acting as potential interface between pastoral and wildlife contexts and the trading system, therefore highlighting the importance of improving the understanding of its role for more evidence-based management of animal health in the country and the wider region.

Appendices

Appendix A

Livestock Market Survey

M |_|_|	|_|_|_|_|
ID of market	ID of Manager

Name of the interviewer: ________________________ **Date:** day \|__¦__\| month \|__¦__\| 201__

1. Market Manager Information

1.1 What is your full name ? ________________________________

1.2 How long have you been working as the manager in this market? ____________________________________

1.3 How are animals mainly brought to this market? (Rank the options it in order of importance, give them the same rank to equally important).

(1) On foot	(2) Motor vehicle	(3) Train	(4) Others

Comments:____
____

1.4 What animals, other than cattle, are currently traded in this market? (Rank options in order of importance, give them the same rank to equally important).

(1)Sheep	(2)Goats	(3)Poultry	(4) Horses	(5) Other

1.5 Do these animals mix themselves at the market? Yes ☐ No ☐

1.6 Did any of the cattle at the market in the past 12 months have FMDV when brought to the market? Yes ☐ No☐

1.7 How many animals? 0% ☐ <10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ other ☐ : _______________

According to your experience when herdsmen and buyem-sellem saw an animal with FMDV in the market, did they:

	Yes	No	Unknown
(**1.8**) use the disease to reduce the price	☐	☐	☐
(**1.9**) buy it if the animal looked strong	☐	☐	☐
(**1.10**) arrange to buy it when it recovered	☐	☐	☐
(**1.11**) not buy it	☐	☐	☐

Comments:____

1.12 Would an outbreak of FMD alter the itineraries of the traders and cattle? Yes ☐ **No** ☐
If yes, how?
____
____

Figure A.1: Questionnaire for interviews with the veterinary services *(Questionnaires Q_1)*

1.13 Are there variations in the cattle price during the dry and wet seasons? Yes ☐ No ☐

1.14 If yes, in which season the price is usually higher: ☐ rainy season ☐ dry season

1.15 If yes, how much variation? <10% ☐ 10-30% ☐ 30-50% ☐ >50% ☐

1.16 *ONLY FOR NORTHWEST REGION*: Which type of cattle usually has a higher price? Indicate a price range:

	White Fulani	Red Fulani	Goudali	Mbororo	Mixed
Range in CFA					

1.17 On average how many dealers are attending a market day?

	Buyem-Sellem	Herdsmen	Butcher	Other
Dry Season				
Wet Season				

Other: ____

1.18 MARKET TRANSACTION COSTS:

Each traded animal	CFA
Buyer	
Seller	

	CFA
Access the market	
Travel Documents	

1.19 Which are the main transhumance destinations of cattle herds normally grazing in this Vet. Center area?

Village\Market	Subdivision	Division	Region*	N° of walking days
1				
2				
3				
4				
5				
6				

***If another country, specify here :**

____

2. Marketing Information

A – RAINY SEASON in the past year

2.1 A) How many cattle were approximately traded on average in each market day?

Kind of cattle	Adult cows	Adult bulls	Young bulls (< 18 moths)	Young calves (< 18 moths)	Cow + calve
Average Number					

B) ***ONLY FOR NORTHWEST REGION*****: What kind of cattle was traded in this market? (Rank options in order of importance, give the same rank to equally important ones.)**

White Fulani	Red Fulani	Goudali	Mbororo	Mixed

2.2 According to your knowledge where were the cattle traded in this market COMING FROM?

Village\Market	Subdivision	Division	Region*	N° of walking days	N° of hours by truck
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

***If another country, specify here :**

____

____

____

2.3 According to your knowledge where were the cattle traded in this market DIRECTED?

Village\Market	Subdivision	Division	Region*	N° of walking days	N° of hours by truck
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

***If another country, specify here :**

____

____

____

2.4 What was the average price per head?

Kind of cattle	Adult cows	Adult bulls	Young bulls (< 18 moths)	Young calves (< 18 moths)	Cow + calve
Average Price					

B – DRY SEASON in the past year

THE SAME OF THE WET SEASON ☐ OR:

2.5 A) How many cattle were approximately traded on average in each market day?

Kind of cattle	Adult cows	Adult bulls	Young bulls (< 18 moths)	Young calves (< 18 moths)	Cow + calve
Average Number					

B) *ONLY FOR THE NORTHWEST*: What kind of cattle was traded in this market? Rank options in order of importance, give the same rank to equally important ones.

White Fulani	Red Fulani	Goudali	Mbororo	Mixed

2.6 According to your knowledge where were the cattle traded in this market COMING FROM?
Same of wet season ☐ or:

Village\Market	Subdivision	Division	Region*	N° of walking days	N° of hours by truck
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

***If another country, specify here :**

____

____

____

2.7 According to your knowledge where were the cattle traded DIRECTED? Same of wet season ☐ or:

Village\Market	Subdivision	Division	Region*	N° of walking days	N° of hours by truck
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					

***If another country, specify here :**

____

____

____

2.8 What was the average price per head? Same of wet season ☐ or:

Kind of cattle	Adult cows	Adult bulls	Young bulls (< 18 moths)	Young calves (< 18 moths)	Cow + calve
Average Price					

4. Conclusion

4.1 During the last year, were sold or bought more cattle during religious celebrations, and/or during other specific commemoration or periods? Yes ☐ No ☐

If yes, specify :

Commemoration/period	Number of cattle sold & bought during this period per day
	Min l______l Max l______l
	Min l______l Max l______l
	Min l______l Max l______l

4.2 Could you list 3 main cattle diseases you see in this market and the period in which they occur?

Disease	Period (Months of the Year)

4.3 Could you list the 3 most significant markets in this Division?

1. ________________________________
2. ________________________________
3. ________________________________

4.4 Could you list the 5 most significant villages in terms of animal population in the area around this Veterinary Centre:

1. ________________________________

2. ________________________________

2. ________________________________

4. ________________________________

5. ________________________________

4.5 <u>Did the patterns of movements changed in past 5 years?</u> (Is the number of cattle traded increased or reduced? Did origins and destinations of animals changed?)

____
____
____

4.6 Do you have some COMMENTS on the cattle movements through this market and this region in general? Or any SUGGESTIONS to help identify the main trades routes of movement of cattle from other regions or countries?

____
____
____

We may need to contact you to clarify some of your answers. Could you please give us your mobile number? (optional)

____

THANK YOU FOR YOUR PARTICIPATION IN THIS SURVEY!

M |__|__|	|__|__|__|__|
ID of market	ID of seller/buyer

Name of interviewer: _______________________ **Date:** day |__|__| month |__|__| 201__ **GPS:** ________________________

1. Herdsman/Trader Information

1.1 a) What is your full name ? ____ **b) How old are you?** years_____

c) STAKEHOLDER STATUS : Who are you in regard to the cattle presented? :

☐ Herdsmen/owner (1) ☐ Buyem-Sellem (2) ☐ Caretaker/laborer (3) ☐ Other (4) :____________________

d) Gender : ☐ Male ☐ Female **Education level :** Secondary ☐ Intermediate ☐ Primary ☐ None ☐

e) What is your ethnic group? ____

1.2 Where is the usual location of your herd.

Village________________ Subdivision__________________ Division__________________ Region _________________

1.3 How do you bring the animals to this market or to your village?

☐ On foot (1) ☐ Motor vehicle (2) ☐ Common carriers (3) ☐ Train (4) ☐ Others (5) ___________________

Commentaires**:**____

____

1.4 What other animals, other than cattle, do you usually meet and mix on the way to the market? Tick the appropriate box:

(1) Any	(2)Sheep	(3)Goats	(4)Poultry	(5)Dogs	(6)Horses	(7)Wild animals	(8)Other

1.5 From all the cattle bought and sold over the past 12 months, how many did you buy in markets and how many outside?

	Markets	**Ouside Markets**
Bought (Num.)		
Sold (Num.)		

Figure A.2: Questionnaire for interviews with other market stakeholder's *(Questionnaires Q_2)*

1.6 How many cattle did you sell in the past year?

	Dry Season	Rainy Season
Number of cattle		

1.7 How many cattle did you buy in the past year?

	Dry Season	Rainy Season
Number of cattle		

1.8 FOR THE NORTHWEST REGION: Which breed of cattle do you mainly trade? (in percentage)

	White Fulani	Red Fulani	Goudali	Mbororo	Mixed
Percentage (They all have to add up to 100%)					

1.9 Did any of the cattle you bought at the market in the last 12 months, developed FMDV? Yes ☐ No☐

1.10 How many animals? ____

1.11 Would you buy an animal if there were FMDV in the area? Yes ☐ No ☐

If you saw an animal with FMDV or another disease in the market, would you:

	Yes	**No**	**Unknown**
(**1.12**) use the disease to reduce the price	☐	☐	☐
(**1.13**) buy it if it looked a strong animal	☐	☐	☐
(**1.14**) arrange to buy it when it recovered	☐	☐	☐
(**1.15**) not buy it	☐	☐	☐

Others:____

1.16 When you buy a new bovine you introduce it in your herd:

Same day ☐ 2-7 days ☐ 1-4 weeks ☐ more ☐ : _____________________________

1.17 Do you bring/send your herd/s on transhumance? Yes ☐ No

If yes: Where? ________________________________ Region: __________________ Division: __________________

If yes: When? From: __________________ To: __________________

2. Today's activities

A - If the interviewed BUYS cattle

2.1 Which villages/markets have THE CATTLE visited before? Can you name them in the TEMPORAL ORDER?

BEFORE					
LOCATION					PLACE
Village	**Subdivision**	**Division**	**Region***	**Days of walk (or hours by truck)**	
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐

2.2 Which villages/markets are THE CATTLE YOU BOUGHT going to after this market? (TEMPORAL ORDER)

NEXT					
LOCATION					PLACE
Village	**Subdivision**	**Division**	**Region***	**Days of walk (or hours by truck)**	
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐

H = Home/Village; M = Market; S = Slaughterhouse; T = Transhumance area.

***If another country, specify here :**

____

2.3 How do you bring the animals to the market or to your village?

☐ On foot (1) ☐ Motor vehicle (2) ☐ Common carriers (3) ☐ Train (4) ☐ Others (5) ___________________

2.4 From whom did you buy?

☐ Buyem-Sellem : How many Buyem-Sellem? ________ Do you know where they are from?: _____________________

☐ Herdsmen: How many Herdsmen? ________ Do you know where they are from?: _____________________

☐ Others:

2.5 A) How many cattle did you buy today?

	Adult cows	Adult bulls	Young bulls	Young calves	Cow + calve
Number					

B) ***ONLY FOR THE NORTHWEST*****: Which breed of cattle are they**

	White Fulani	Red Fulani	Goudali	Mbororo	Mixed
Number					

Purpose for buying cattle?

	Yes	**No**	**Unknown**
(**2.6**) Direct to slaughter	☐	☐	☐
(**2.7**) Breeding (ultimately destined for slaughter or re-sale)	☐	☐	☐
(**2.8**) Own consumption	☐	☐	☐

Others: ____

2.9 What was today's average price per head?

Kind of cattle	Adult cows	Adult bulls	Young bulls	Young calves	Cow + calve
Average Price					

2.10 Do you expect variations in the price during the dry and wet seasons? Yes ☐ No ☐

2.11 If yes, in which season the price is usually higher: ☐ rainy season ☐ dry season

2.12 If yes, how much variation? ____

B - If the interviewee SELLS cattle

2.13 How many cattle did you bring to the market today TO SELL? ____

How many cattle did you bring IN TOTAL? ____

2.14 Which villages/markets have THE CATTLE visited before? Can you name them in the TEMPORAL ORDER?

BEFORE					
LOCATION					PLACE
Village	**Subdivision**	**Division**	**Region***	**Days of walk (or hours by truck)**	
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐

2.15 Which villages/markets is THE CATTLE YOU HAVE NOT SOLD going to after this market? (TEMPORAL ORDER)

NEXT					
LOCATION					PLACE
Village	**Subdivision**	**Division**	**Region***	**Days of walk (or hours by truck)**	
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐
					H ☐ M ☐ S ☐ T ☐

H = Home/Village; M = Market; S = Slaughterhouse; T = Transhumance area.

***If another country, specify here :**

____

2.16 Who did you sell to?

☐ Buyem-Sellem : How many Buyem-Sellem? _________ Do you where they are from?: _________________________

☐ Herdsmen: How many Herdsmen? _________ Do you where they are from?: _________________________

☐ Others:____

2.17 A) How many cattle did you sell today?

	Adult cows	Adult bulls	Young bulls	Young calves	Cow + calve
Number					

B) ***ONLY FOR THE NORTHWEST*****: Which breed of cattle are they**

	White Fulani	Red Fulani	Goudali	Mbororo	Mixed
Number					

Purpose for selling?

	Yes	**No**	**Unknown**
(**2.18**) Earning money to buy younger animals	☐	☐	☐
(**2.19**) Buy family consumables, taxes, farming inputs	☐	☐	☐
(**2.20**) Unknown	☐	☐	☐

Others:____

2.21 What was today's average price per head?

Kind of cattle	Adult cows	Adult bulls	Young bulls	Young calves	Cow + calve
Average Price					

2.22 Do you expect variations in the price during the dry and wet seasons? Yes ☐ No ☐

2.23 If yes, in which season the price is usually higher: ☐ rainy season ☐ dry season

2.24 If yes, how much variation? ____

2.25 ***ONLY FOR THE NORTHWEST*****: Which type of cattle did you sell at higher price?**

Fulani (1) ☐ Goudali (2) ☐ Mbororo (3) ☐ Mixed (4) ☐ Unknown (5) ☐

4. CONCLUSION

4.1 During the last year, did you sell or buy more cattle during religious celebrations, and/or during other commemoration or periods? Yes ☐ No ☐

If yes, specify :

Celebration/Festivity	Number of cattle sold/bought during this period per day
	Min l______l Max l______l
	Min l______l Max l______l
	Min l______l Max l______l

We may need to contact you to clarify one of your answers. Can you give us your mobile number? (optional)

THANK YOU FOR YOUR PARTICIPATION IN THIS SURVEY

Appendix B

Chapter 6, Supplementary material

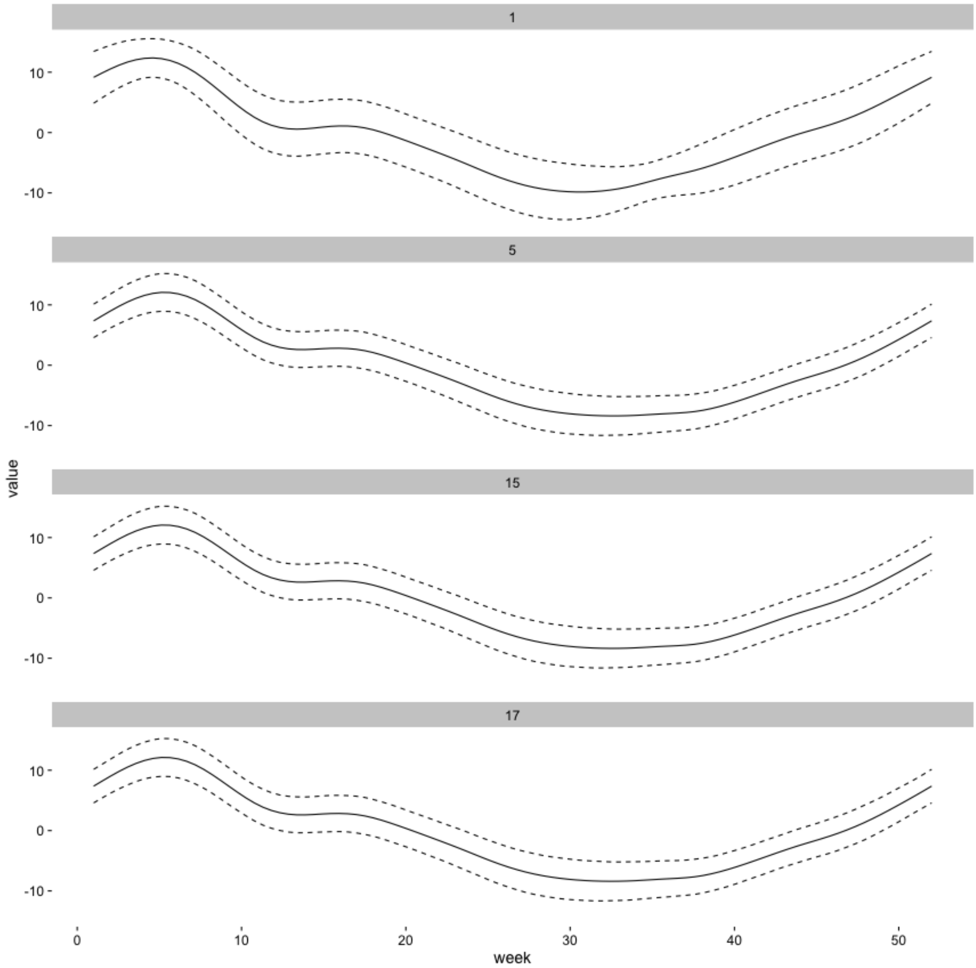

Figure B.1: **Smoothed fits of the week covariate.**
Smoothed fits of the week covariate and its relation with cattle price for the 4 subset models. Tick marks on the x-axis are weeks of observation (1st of September 2013 to 31st of August 2014), and the y-axis represent the spline function. The black dashed line indicate the range smoothed fits for all the 50 iterations; the black solid line the mean smoothed fit.

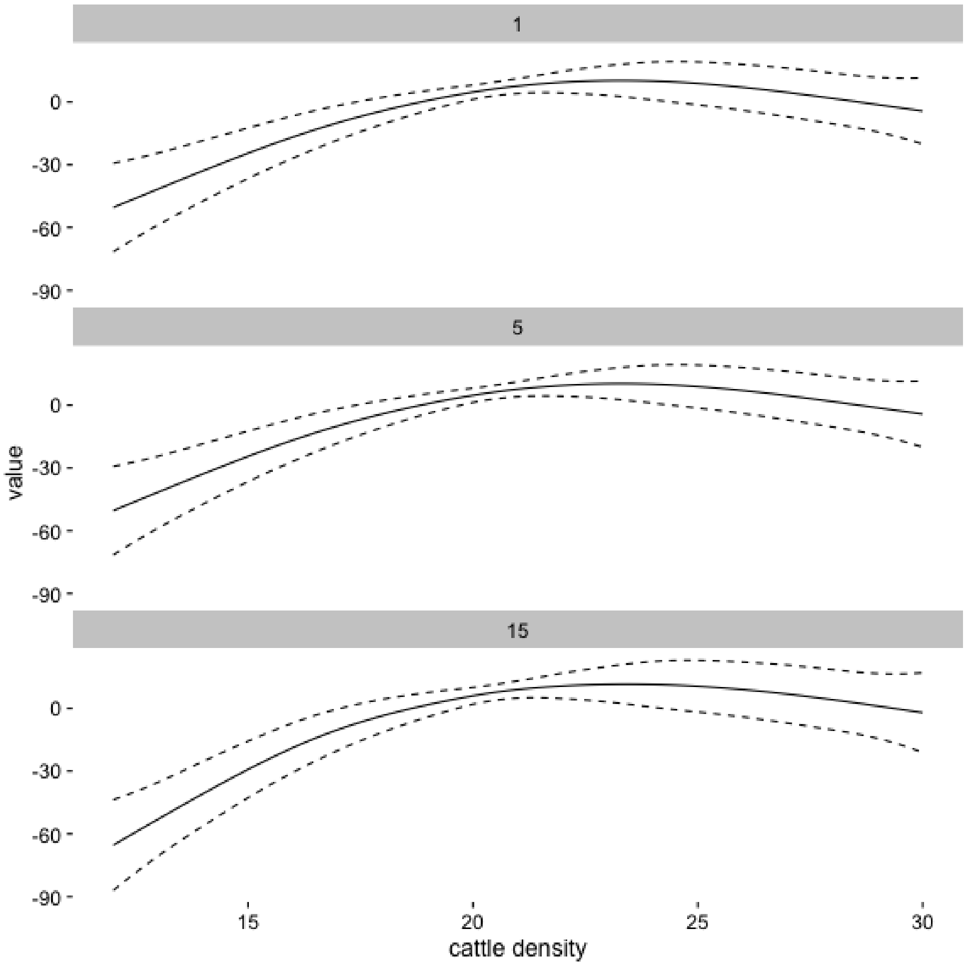

Figure B.2: **Smoothed fits of the cattle density covariate.** Smoothed fits of the cattle density covariate and its relation with cattle price for the 3 subset models including cattle density as a predictor. Tick marks on the x-axis indicate the cattle per squared kilometre, and the y-axis represent the spline function. The black dashed line indicate the range smoothed fits for all the 50 iterations; the black solid line the mean smoothed fit.

Table B.1 Variables and goodness-of-fit measures, and their 95% range, for all models considered.

Model	x_k	z_m	R^2	**ΔAIC**	ϕ
1	HD+IDEG+SEAS+DIV	CD+T	47.4 (42.3, 50.1)	-91.1 (-103, -81.2)	82%
2	HD+SEAS+DIV	CD+T	46.8 (45.2, 48.2)	-81.1 (-89.5, -74.8)	0%
3	HD+IDEG+SEAS	CD+T	44.9 (43.9, 46.8)	-41.7 (-46.2, -37.3)	0%
4	HD+SEAS	CD+T	43.4 (43.9, 46.8)	-36.2 (-41.2, -31.9)	0%
5	HD+IDEG+DIV	CD+T	47.4 (45.6, 49.3)	-88.0 (-99.4, -78.8)	18%
6	HD+DIV	CD+T	46.8 (45.2, 48.6)	-77.9 (-86.1, -72.1)	0%
7	IDEG+SEAS+DIV	CD+T	45.0 (43.4, 46.8)	-26.8 (-31.7, -22.6)	0%
8	SEAS+DIV	CD+T	44.2 (42.6, 46.1)	-24.9 (-30.4, -16.6)	0%
9	HD+IDEG+SEAS+DIV	T	43.6 (42.6, 45.6)	-28.5 (-33.6, -24.4)	0%
10	HD+SEAS+DIV	T	37.8 (36.2, 40.1)	-18.6 (-22.0, -18.6)	0%
11	IDEG+SEAS	T	42.3 (41.0, 44.2)	-7.9 (-11.5, -5.9)	0%
12	SEAS	T	39.7 (38.2, 41.6)	-3.1 (-6.9, -1.9)	0%
13	HD+IDEG	CD+T	44.9 (43.3, 46.7)	-38.6 (-42.3, -34.5)	0%
14	HD	CD+T	43.4 (42.7, 45.2)	-33.0 (-36.3, -29.1)	0%
15	IDEG+DIV	CD+T	46.2 (44.3, 48.6)	-67.8 (-76.3, -61.8)	0%
16	DIV	CD+T	46.6 (45.1, 48.6)	-65.3 (-70.2, -60.0)	0%
17	HD+IDEG+DIV	T	46.1 (44.8, 48.4)	-70.3 (-75.6, -65.4)	0%
18	HD+DIV	T	45.3 (43.9, 47.2)	-62.1 (-66.0, -59.1)	0%
19	HD	CD	42.3 (41.0, 44.2)	-4.7 (-6.5, -3.2)	0%
20	IDEG	CD+T	39.6 (38.2, 41.6)	0.0 (0.0, 0.0)	0%
21	HD+IDEG	T	43.6 (42.2, 45.7)	-25.3 (-28.3, -21.5)	0%
22	HD	T	37.8 (36.3, 40.0)	-15.4 (-17.4, -14.0)	0%
23	IDEG	T	44.9 (43.3, 46.8)	-23.7 (-26.9, -19.8)	0%
24	–	T	44.2 (42.6, 46.0)	-21.7 (-25.4, -16.8)	0%

x_k: Linear predictor variables; z_m: non-linear predictor variables; R^2: Adjusted coefficient of determination between observed and predicted data; ΔAIC: Difference of Akaike information criterion between models; ϕ: Number of iterations in which candidate model returned the lowest AIC value over the 50 bootstrapped iterations.
Linear predictor variables: HD: Human density; IDEG: Market-level centrality measure as defined by in-degree; SEAS: Season at which transaction occurred; DIV: Administrative division of the market.
Non-linear predictor variables: CD: Cattle density of the market; T: Week at which transaction occurred.
For all models, age and sex of the animal involved in each recorded transaction were included as linear predictor variables, whereas market at which transaction occured was included as random effect.

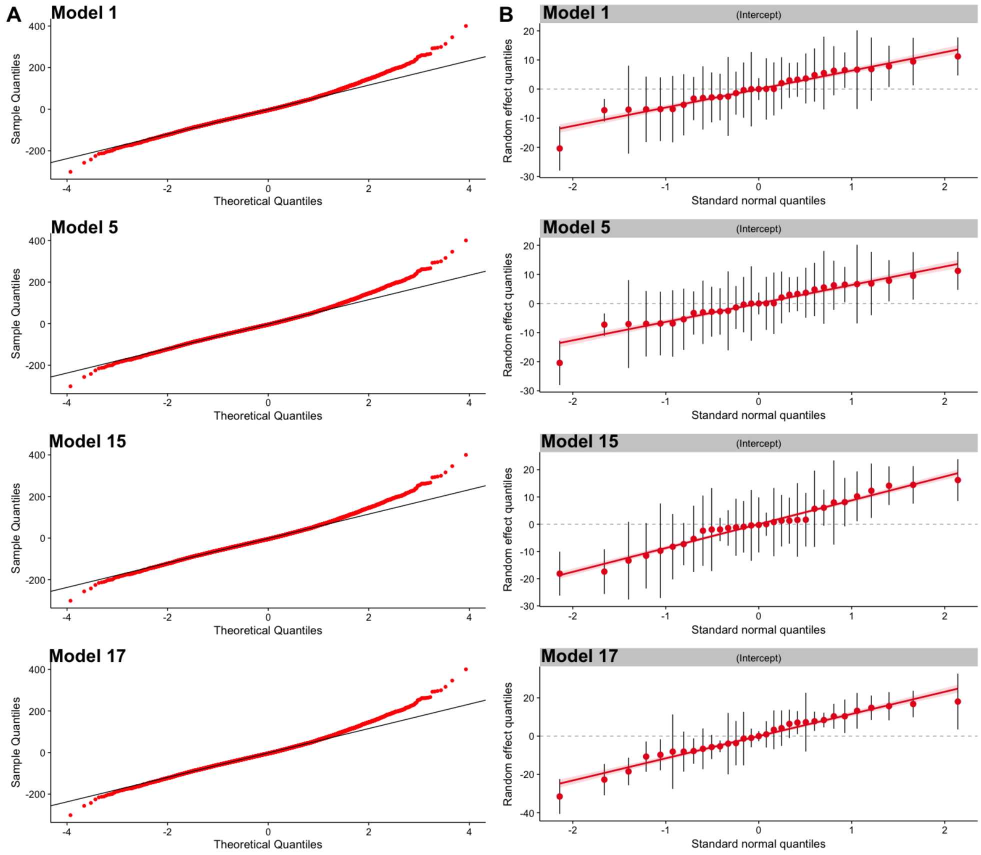

Figure B.3: **Quantile-quantile plots for the *fixed* and *random effects* for the subset models.**
Figure A: Distributions of the residuals errors for the *fixed effects* included in the final model. Figure B: Distributions of the residuals for the *random effect* (cattle market)

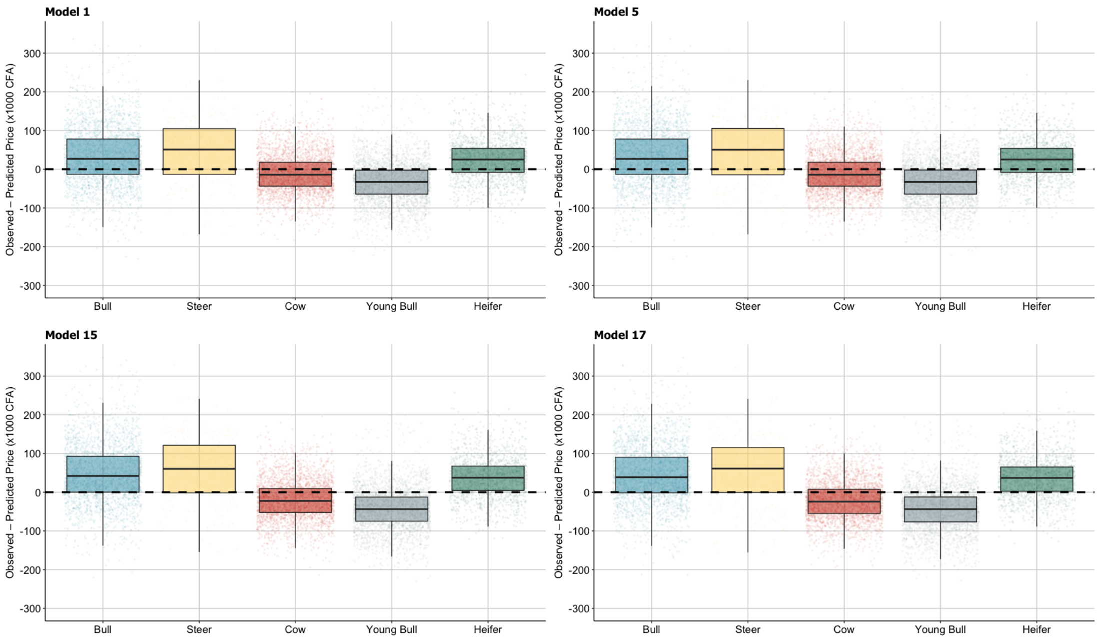

Figure B.4: **Predictive ability of the model.**
Visualization of cross-validation output. Observed prices of live cattle at the market level are displayed on the x axis and fitted values on the y axis (prices are in x1000 CFA). In the top left of the figure are displayed the values of the adjusted R^2, MAE and the CV. The dotted black line represents the 1:1 identity line.

Table B.1: Cross-validation outputs for the model selection. The predictive ability of models 1, 5, 15 and 17 are compared based on the value of the mean absolute error (MAE), the coefficient of variation (CV) and the adjusted coefficient of determination (R^2)

	MAE	CV	adjusted R^2
Model 1	9.6 (47.6-51.3)	27.7 (24.9-29.2)	47.4% (42.3-50.1)
Model 5	49.6 (47.9-51.0)	27.7 (24.9-28.9)	47.4% (45.6-49.3)
Model 15	49.9 (48.3-52.4)	27.9 (25.9-29.6)	46.9% (44.3-48.6)
Model 17	49.9 (48.4-52.4)	27.9 (26.0-29.8)	46.9% (44.8-48.4)

Appendix C

Transhumant Herds Study

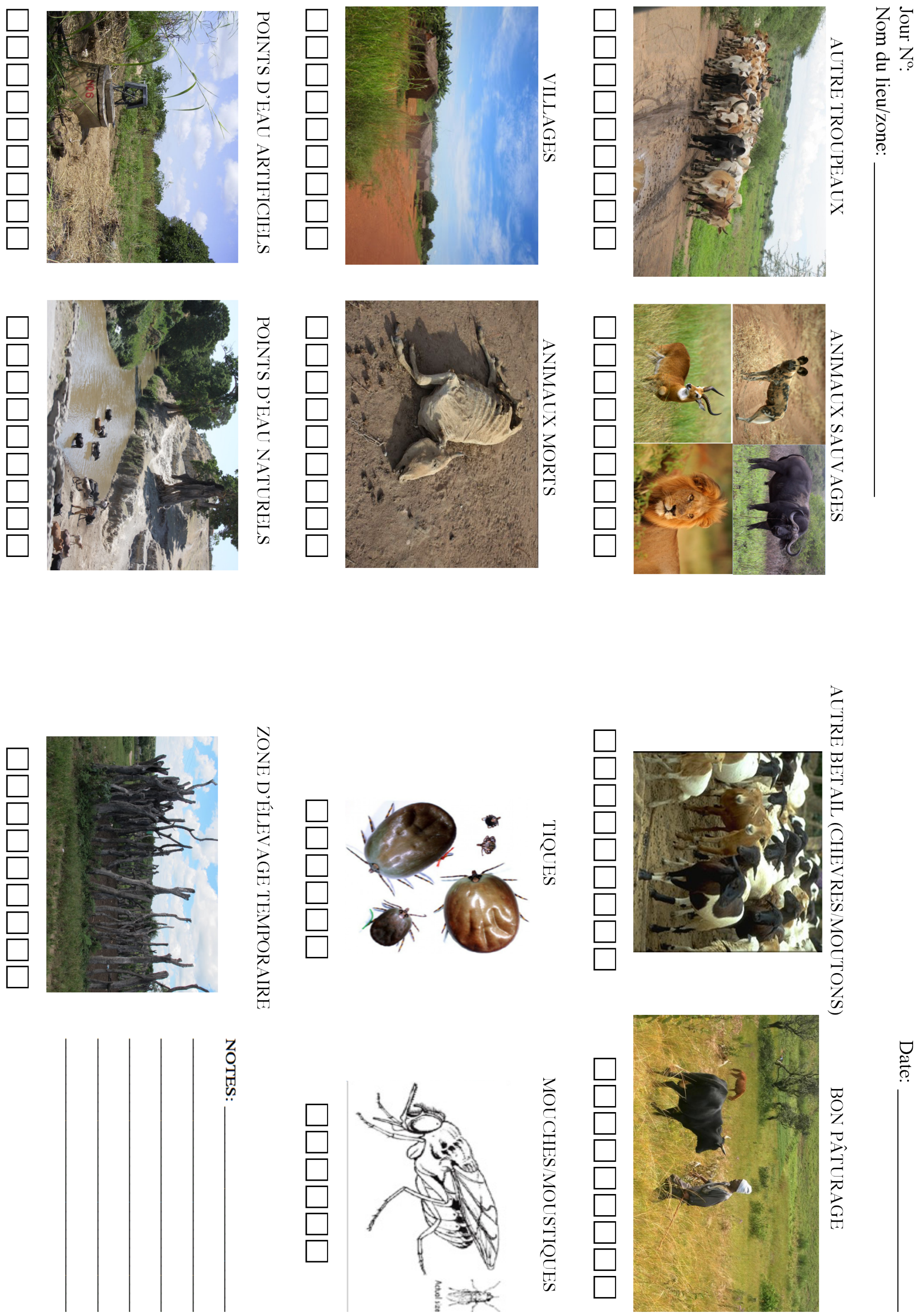

Figure C.1: **Page example of the pictorial diaries (G_2).**

Transhumance Questionnaire

Name of interviewer: _______________________ **Date:** day |__¦__| month |__¦__| 201__ **GPS:** _______________________

1. HERDSMAN INFORMATION

1.1 a) What is your full name ? ____ **b) How old are you?** years_____

c) STAKEHOLDER STATUS : Who are you in regard to the cattle presented? :

☐ Herdsmen/owner (1) ☐ Buyem-Sellem (2) ☐ Caretaker/laborer (3) ☐ Other (4) :_____________________

d) Gender : ☐ Male ☐ Female **Education level :** Secondary ☐ Intermediate ☐ Primary ☐ None ☐

e) What is your ethnic group? ____

2. HERD/TRANSHUMANCE INFORMATION

2.1 a) When did the herd left for on transhumance?______________

b) When did it return to the usual location?_____________

2.2 Where is the usual location of this herd?

Village________________ Subdivision__________________ Division__________________ Region _________________

2.3 Where was the main area of transhumance for this herd?

Village________________ Subdivision__________________ Division__________________ Region _________________

2.4 How many days of walk from the usual location of the herd? ________________________________

2.5 During this period of trekking how many hours per day was the herd walking? ____________and grazing?__________

2.6 Once reached the transhumant area how many hours per day was the herd walking? _________and grazing?________

1

Figure C.2: Questionnaire for interviews with the herdsmen of transhumant herds *(Questionnaires G_3)*

2.7 Are there other areas where the herd was located during this period?

Village________________ Subdivision__________________ Division__________________ Region _________________

Village________________ Subdivision__________________ Division__________________ Region _________________

Village________________ Subdivision__________________ Division__________________ Region _________________

2.8 How many herds on average have your herd contacted on a daily basis in the transhumance area?

0 ☐ 1-3 ☐ 4 - 5 ☐ 5 - 10 ☐ 10 - 15 ☐ > 15 ☐

2.9 How many herds on average have your herd contacted on a daily basis during the trekking to the transhumance area?

0 ☐ 1-3 ☐ 4 - 5 ☐ 5 - 10 ☐ 10 - 15 ☐ > 15 ☐

2.10 How long this interaction was lasting on average?

<1 hour ☐ 1-2 hours ☐ 3-6 hours ☐ 6 - 12 ☐ 12 – 24 hours ☐ 1 -2 days ☐ 2-4 days ☐

more ☐ : ______________________________________

2.11 How long did the longest interaction lasted?

<1 hour ☐ 1-2 hours ☐ 3-6 hours ☐ 6 - 12 ☐ 12 – 24 hours ☐ 1 -2 days ☐ 2-4 days ☐

more ☐ : ______________________________________

2.12 What other animals, other than cattle, did the herd come into contact during this period?

(1)Sheep	(2)Goats	(3)Poultry	(4)Dogs	(5)Horses	(6) Pigs	(7) Buffaloes	(8)Antelope	(9) Warthog	(10)Other

2.13 Which of the previous animals did the herd meet more frequently? _________________________________

2.14 From which of the following the cattle were drinking from during transhumance?

(1)natural water troughs	(2) artificial canals	(3)streams	(4)lakes/pounds

2.15 How many other herds did your herd meet at these watering points on average?

0 ☐ 1-3 ☐ 4 - 5 ☐ 5 - 10 ☐ 10 - 15 ☐ > 15 ☐

2.16 How many other herds used the same watering points in your knowledge?

0 ☐ 1-3 ☐ 4 - 5 ☐ 5 - 10 ☐ 10 - 15 ☐ > 15 ☐

2.17 Have the cattle grazed on flooded or swampy pasture while on transhumance? Yes ☐ No ☐

2.18 Have you sold or bought any cattle during the transhumance period? Yes ☐ No☐

	Markets	**Ouside Markets**
Bought (Num.)		
Sold (Num.)		

2.19 Purpose for buying cattle?

	Yes	**No**	**Unknown**
(**2.20**) Direct to slaughter	☐	☐	☐
(**2.21**) Breeding (ultimately destined for slaughter or re-sale)	☐	☐	☐
(**2.22**) Own consumption	☐	☐	☐

Others: ____

2.23 Purpose for selling?

	Yes	**No**	**Unknown**
(**2.24**) Earning money to buy younger animals	☐	☐	☐
(**2.25**) Buy family consumables, taxes	☐	☐	☐
(**2.26**) To treat other animals	☐	☐	☐

Others: ____

3. INFECTIOUS DISEASES

3.1 How many animals were borne during the transhumance? ________________________________

3.2 How many animals died during the transhumance? ________________________

3.3 If animals died which was the cause of death:

	Yes	No	Number of animals
(3.4) Accident	☐	☐	
(3.5) Disease	☐	☐	
(3.6) Hunger/Thirst	☐	☐	
(3.7) Other	☐	☐	

3.8 Did any of the cattle developed FMD during the transhumance period? Yes ☐ No☐

3.9 How many animals? ____

3.10 Have any of them died of FMD? Yes ☐ No☐

3.11 How many animals? ____

3.12 How many herds infected with FMD did you meet during transhumance ? _________________________________

3.13 Which are the main 3 diseases that you observed on the animals in your and other herds during transhumance? And in which month?

Disease	Number of animals	Month

3.14 Have you treated your herd for some disease during transhumance? Yes ☐ No☐

For which diseases? ____

3.14 When you buy a new bovine you introduce it in your herd:

Same day ☐ 2-7 days ☐ 1-4 weeks ☐ more ☐ : ______________________________

4. CONCLUSION

4.1 A) Do you think you will take this herd to the same are next year? Yes ☐ No☐

B) If no, why?

____

____

C) If no, where do you plan to go?

____

____

4.2 Did you have conflicts with other herds over the grazing pasture? Yes ☐ No☐

If yes, what was the cause?

____

____

4.3 What is the composition of the herd that went on transhumance?

Cows	Bulls	Young Bulls (<3 years)	Heifers (<3 years)	Veals

We may need to contact you to clarify one of your answers. Can you give us your mobile number? (optional)

____

THANK YOU FOR YOUR PARTICIPATION IN THIS SURVEY

Appendix D

List of published and submitted manuscripts

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SCIENTIFIC REPORTS

OPEN

Implications of the cattle trade network in Cameroon for regional disease prevention and control

Received: 09 August 2016
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Paolo Motta[1,2], Thibaud Porphyre[1], Ian Handel[2], Saidou M. Hamman[3], Victor Ngu Ngwa[4], Vincent Tanya[5], Kenton Morgan[6], Rob Christley[7,8] & Barend M. deC. Bronsvoort[1,2]

Movement of live animals is a major risk factor for the spread of livestock diseases and zoonotic infections. Understanding contact patterns is key to informing cost-effective surveillance and control strategies. In West and Central Africa some of the most rapid urbanization globally is expected to increase the demand for animal-source foods and the need for safer and more efficient animal production. Livestock trading points represent a strategic contact node in the dissemination of multiple pathogens. From October 2014 to May 2015 official transaction records were collected and a questionnaire-based survey was carried out in cattle markets throughout Western and Central-Northern Cameroon. The data were used to analyse the cattle trade network including a total of 127 livestock markets within Cameroon and five neighboring countries. This study explores for the first time the influence of animal trade on infectious disease spread in the region. The investigations showed that national borders do not present a barrier against pathogen dissemination and that non-neighbouring countries are epidemiologically connected, highlighting the importance of a regional approach to disease surveillance, prevention and control. Furthermore, these findings provide evidence for the benefit of strategic risk-based approaches for disease monitoring, surveillance and control, as well as for communication and training purposes through targeting key regions, highly connected livestock markets and central trading links.

Movements within and between populations are a central driver of disease dynamics defining the patterns of interactions and the susceptibility to the spread of a wide range of infectious agents[1–4]. Livestock trade is of particular importance, since pathogens can be transmitted over long distances via movement of infectious animals. Understanding the structure of livestock contacts and studying the routes, volumes, frequency and the risks associated with animal movement represents a prerequisite for effective animal and zoonotic disease surveillance and control. Most industrialised countries have implemented animal identification, registration and tracing systems to enhance strategic and targeted approaches for disease surveillance, to develop early warning systems for outbreak detection and for more informed control measures[5]. However, in most lower income countries, where the presence of endemic diseases represents an obstacle for the development of animal trade and the improvement of the livestock sector as a whole, there is still limited information on livestock movements with no systematic recording systems[6].

Currently some of the world's most rapid urbanization is taking place in West and Central Africa, where the population is poised to quadruple in size by the end of this century[7]. As *per capita* consumption of animal-source foods is projected to continue rising and even to accelerate in the short-medium term[8], the volume of livestock trade is likely to expand in this region. In West and Central Africa livestock have traditionally been raised in semi-arid regions to be traded in forested zones and urban areas[9]. These long distance, and often cross-border,

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Figure D.1: *Motta, P. et al. Implications of the cattle trade network in Cameroon for regional disease prevention and control. Sci. Rep. 7, 43932; doi: 10.1038/srep43932 (2017)*

Drivers of live cattle price in the livestock trading system of Central Cameroon

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word count abstract (max 350): 282
word count main text (max 12,000): 5,976

ABSTRACT

Livestock production and trade are critical for the food security and welfare of rural households in sub-Saharan Africa. In Cameroon, animal trade consists mainly of live cattle commercialized through livestock markets. Identifying the factors contributing to cattle price formation is critical for designing effective policies for sustainable production and for increasing food availability. In this study, we evaluated the influence of a range of individual- and market-level factors on the price of cattle that were sold in all transactions (n=118,017) recorded over a 12-month period from 31 livestock markets in the main cattle production area of the country. An information-theoretic approach using a generalized additive mixed-effect model was implemented to select the best explanatory model as well as evaluate the robustness of the identified drivers and the predictive ability of the model. The age and gender of the cattle traded were consistently found to be important drivers of the price ($p<0.01$). Also, strong, but complex, relationships were found between cattle prices and both local human and bovine population densities. Finally, the model highlighted a positive association between the number of incoming trading connections of a livestock market and the price of the traded live cattle ($p<0.01$). Although our analysis did not account for factors informing on specific phenotypic traits nor breed characteristics of cattle traded, nearly 50% of the observed variation in live cattle prices was explained by the final model.

Figure D.2: *Motta, P. et al. Drivers of live cattle price in the livestock trading system of Central Cameroon. Under review*

Cattle transhumance and agropastoral nomadic herding practices in Central Cameroon

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word count abstract (max 350): 273
word count main text (max 12,000): 4,976

ABSTRACT

In sub-Saharan Africa, livestock transhumance represents a key adaptation strategy to environmental variability. However, movement of live animals is a central driver of disease dynamics and the seasonal transhumance represents a key risk factor for the spread of a number of livestock infectious diseases such as foot-and-mouth disease.
During the dry season, cattle transhumance is a common practice across all the main livestock production zones in Cameroon. Currently, there is little recorded information of the migratory routes, grazing locations and nomadic herding practices adopted by pastoralists, which limits our understanding of cattle movements in the country. This knowledge is important for the development of evidence-based approaches for animal health management.
GPS-tracking technology in combination with a questionnaire based-survey were used to study a pool of 10 cattle herds from the Adamawa Region of Cameroon during their seasonal migration between October 2014 and May 2015. The data were used to analyse the trajectories and herding

Figure D.3: *Motta, P. et al. Cattle transhumance and agropastoral nomadic herding practices in Central Cameroon. Under review*

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